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A STRUCTURE SECTION ACROSS THE CANADIAN ROCKIES

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ABSTRACT

The portion of the Canadian Rockies along the line of the Canadian Pacific Railway has been much studied, but recent work allows the presentation of a section which shows some information additional to what has been previously published. The section is described, with a brief résumé of the geological history of the region.

The sessions of Harvard Summer School of Field Geology were held in the Canadian Rockies in 1924, 1925, and 1927. A part of the time each season was devoted to interpreting a new structure section across the mountains along the main line of the Canadian Pacific Railroad. Many former assistants and students in the course have contributed to the results here presented.

This section, the most accessible in the mountains, has been studied by many geologists, and two profile sections have already been published. The first, by McConnell,[1] is somewhat generalized, since it was the result of reconnaissance at a time when very little was known about the fossils of the region. The second, by J. A. Allan,[2] is a very accurate and detailed section, from which ours differs principally because it takes a somewhat different course. Dr.

[1] *Geol. Surv. of Can. Ann. Rept.*, Vol. II (1887).

[2] *Geol. Surv. of Can. Guide Book*, No. 8, Part II (1913).

Allan's section was carried approximately parallel to the strike from Hole-in-the-Wall to Mount Temple, whereas ours has been offset along the Sawbacks, in an effort to keep as nearly as possible at right angles to the strike. We have also added the structure from Cascade River to the Rocky Mountain front. Our section from Mount Denis westward has been taken directly from Dr. Allan's.

Dowling[1] shed a great deal of light on the nature of the thrusts in this region by his accurate mapping in the Cascade coal basin. Warren[2] has mapped and described the region about Banff, and Allan's[3] map and report of the area about Field are invaluable. Walker's[4] report and map of the Windermere region clarify much that was previously obscure about the relationships of the strata east and west of the Rocky Mountain trench, and Schofield[5] and Shepard[6] have added to our knowledge of the regions southeast and northwest of that area. Walcott's[7] work on the Cambrian and Ordovician is of course of fundamental importance, and Shimer[8] has helped much in the understanding of the Devonian and Carboniferous. Kindle[9] and Burling[10] have also contributed to the progress which has been made in the understanding of the stratigraphy and correlation.

It may seem invidious to single out particular individuals for especial mention, when so many former assistants and students have given assistance, but we cannot refrain from tendering our especial thanks to Professor T. H. Clark, Mr. H. C. Stetson, Mr. Forbes Hutchins, Mr. James S. Pass, and Mr. Donald Reynolds for their unselfish labors toward the solution of the problems involved in this section.

THE STRATA INVOLVED IN THE STRUCTURE

To understand the structure it is necessary to know something of the strata involved. The following composite sections will give some idea of the strata which exist in the region either along the

[1] *Geol. Surv. of Can. Pub. 949* (1907.)
[2] *Geol. Surv. of Can. Mem. 153* (1927).
[3] *Geol. Surv. of Can. Mem. 55* (1914).
[4] *Geol. Surv. of Can. Mem. 148* (1926).
[5] *Geol. Surv. of Can. Mem. 76* (1915).
[6] *Jour. of Geol.*, Vol. XXX (1922); Vol. XXXIV (1926).
[7] *Smithsonian Misc. Colls.*, Vol. LXXVIII (1928).
[8] *Geol. Surv. of Can. Bull. 42* (1926).
[9] *Pan-American Geologist*, Vol. XLII (1924).
[10] *Geol. Surv. of Can. Bull. 2* (1914).

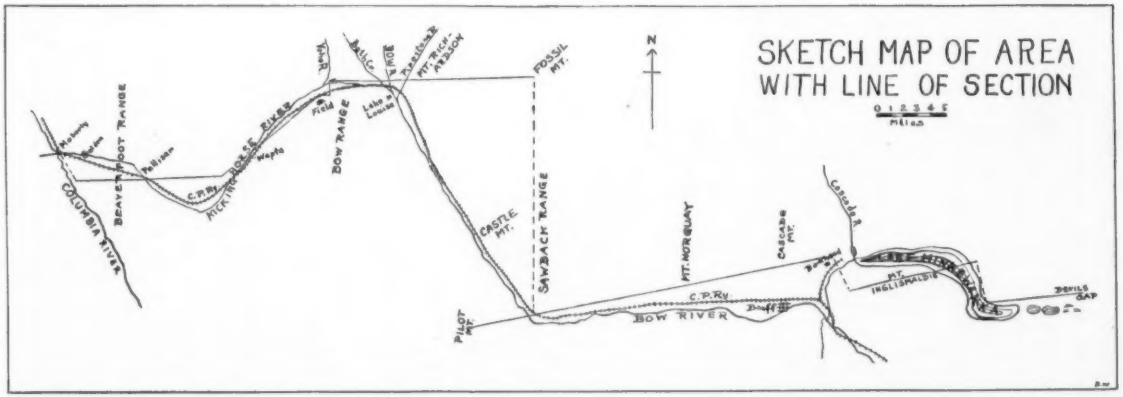

FIG. 1.—Sketch map of area with line of section indicated, showing the line of the geologic section drawn in Fig. 2 and in Fig. 3. Starting at Devils Gap at the Rocky Mountain front, the section runs west to Lake Minnewanka. A short jog along the strike of the formations carries the line north to the east middle of the lake, whence it continues west past another jog near Bankhead, through to Pilot Mountain. A large jog is taken to Fossil Mountain along the strike of Sawback Range. Thence the line runs west to Kicking Horse River, which is approximately followed to Columbia River.

line of the section or in the immediate vicinity. It is at present difficult to say how much has been eroded, since the Laramide revolution, from the western part of the region, or just what lies buried beneath the oldest rocks now visible at the east.

This section does not represent the succession at any one locality, but includes formations both east and west of the Rocky Mountain

TABLE I

SECTION IN THE WINDERMERE MAP AREA—MODIFIED AFTER WALKER AND WALCOTT

		Feet
*Starbird limestone	Upper Devonian	230
*Mount Forster shale	Devonian	600
Brisco limestone	Middle Silurian	1,200
Beaverfoot limestone	Upper Ordovician	400
Wonah quartzite	Upper Ordovician	167
Glenogle shale	Middle and Lower Ordovician	2,162
Sarbach limestone	Lower Ordovician	400±
Mons limestone	Lower Ordovician	3,300
Sabine limestone	Upper Cambrian	742
Elko limestone	Upper Cambrian	2,000
Burton limestone	Middle Cambrian	730
Cranbrook quartzite	Lower Cambrian	675
*Horsethief shale	Pre-Cambrian	4,000+
*Toby conglomerate	Pre-Cambrian	2,000±
*Mount Nelson formation	Pre-Cambrian	3,400+
*Dutch Creek formation	Pre-Cambrian	3,000±

* Chiefly west of the trench in Purcell Mountains.

trench in the Windermere map area and south of it. In the Windermere region the Elko limestone rests on the Horsethief shale, the Middle and Lower Cambrian being absent. The Elko itself is unfossiliferous and consists of limestone which is correlated by Walcott with the Upper Cambrian Lyell formation, and by Walker with the Upper Cambrian Ottertail formation. The Horsethief and Toby are both thin on the eastern side of the trench. The Dutch Creek formation is said by Walker to be the equivalent of the Rosseville, Phillips, and the upper part of the Gateway formations of Daly's section on the international boundary. Still farther south the youngest formation in the trench is the Wardner limestone, of Mississippian age.

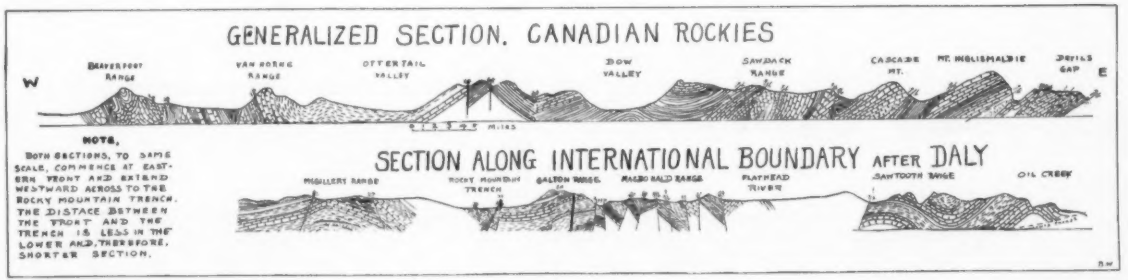

FIG. 2.—Sections across the Canadian Rockies, generalized. The upper section illustrates observed structures along the section line of Fig. 1. Section is generalized and no attempt made to show successive formations. Details are given in Fig. 3. The second section illustrates conditions along the international boundary, after Daly. It will be observed that the areas of faulting in the eastern and western ends of this section are less pronounced than in the more northerly section, particularly the eastern end. This may be because the section on the boundary is made up chiefly of pre-Cambrian rocks which render recognition of faulting difficult. Furthermore, if the faults tend to converge downward into a "sole" it is possible that they have so converged and met in the Lewis thrust with subsequent erosion of younger beds to the south. Note also that there appears to have been a larger area of collapse of the central arch in the southern section.

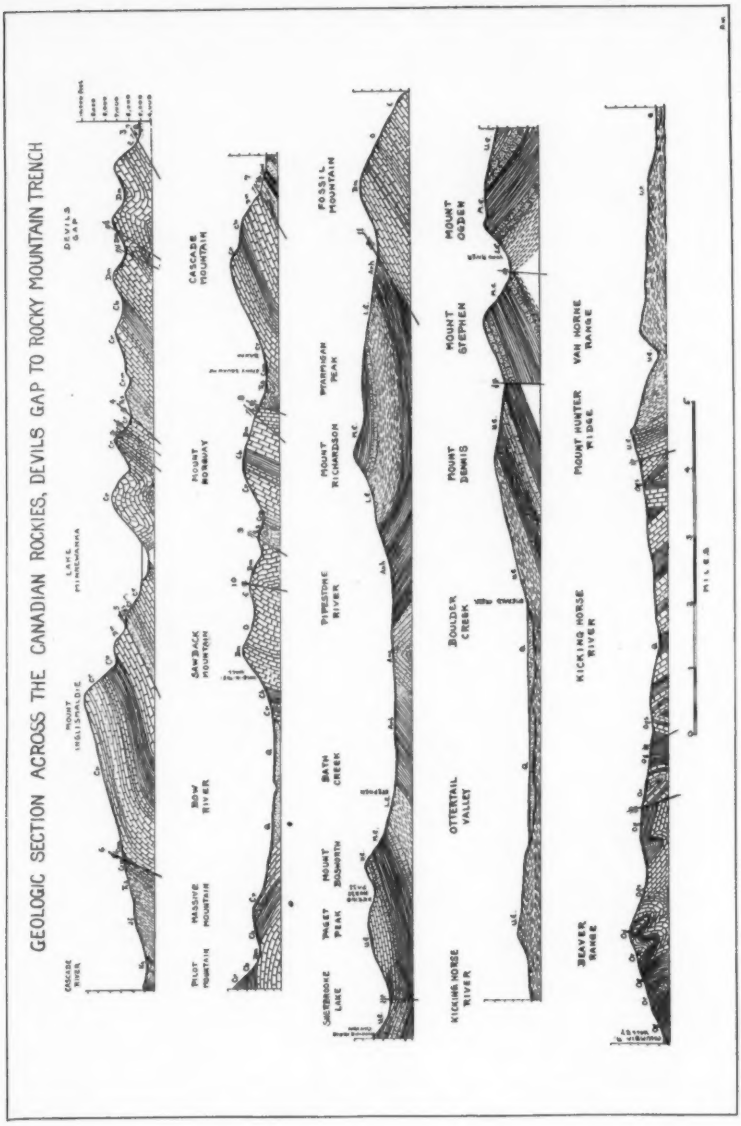

FIG. 3.—Explanation on opposite page

EXPLANATION OF FIGURE 3

FIG. 3.—Geologic section across the Canadian Rockies, Devils Gap to Rocky Mountain Trench, giving in detail the section shown in Fig. 2 (upper). It shows in greater distinctness the structures and also the several formations of various ages.

Pleistocene and Recent	*Q*
Mesozoic	
Cretaceous (Lower)	
Kootenay formation	*Kk*
Jurassic	
Fernie formation	*Jf*
Triassic	
Spray River formation	*Ts*
Paleozoic	
Carboniferous	
Rocky Mountain formation	*Crm*
Rundle formation	*Cr*
Banff formation	*Cb*
Devonian	
Minnewanka formation	*Dm*
Silurian	*S*
Ordovician	
Undifferentiated	*O*
Goodsir formation	*Og*
Glenogle formation	*Ogs*
Cambrian	*Є*
Pre-Cambrian	
Hector formation	*Arh*
Corral Creek formation	*Arc*

The former westward extent of these formations is problematical. The Starbird, Mount Forster, Mons, Sabine, and Cranbrook are definitely known to be present in the Purcell Range; some of the others may have been deposited there, but removed before the end of the Paleozoic.

It will be noted that most of these formations are weak, being composed of shaly limestone or shale. The Beaverfoot, Wonah, and Elko are the only competent beds above the Toby conglomerate.

TABLE II

COMPOSITE SECTION AT AND NORTH OF LAKE LOUISE, ALTA. —AFTER WALCOTT

		Feet
Banff shaly limestone	Mississippian	Thickness unknown
Pipestone limestone	Upper Devonian	1,200
Messines limestone	?Middle Devonian	663
Sarbach limestone	Lower Ordovician	1,090
Mons limestone	Lower Ordovician	980
Sabine limestone	Upper Cambrian	500
Sherbrook limestone	Upper Cambrian	1,375
Paget limestone	Upper Cambrian	360
Bosworth dolomite	Upper Cambrian	1,855
Eldon limestone	Middle Cambrian	2,728
Stephen shale	Middle Cambrian	640
Cathedral limestone	Middle Cambrian	1,595
Ptarmigan shale	Middle Cambrian	664
Mount Whyte limestone	Lower Cambrian	390
St. Piran quartzite	Lower Cambrian	2,705
Lake Louise shale	Lower Cambrian	105
Fort Mountain quartzite	Lower Cambrian	1,000
Hector shale	Pre-Cambrian	1,300
Corral Creek quartzite	Pre-Cambrian	1,200+
		20,350+

The thickness of the Upper Cambrian as given in Table II is undoubtedly incorrect, since the present writers have assumed that the Sabine rests upon the Sherbrook, a relationship for which there is some evidence but no proof.

The only incompetent beds in this section are the rather shaly limestones of the Upper Cambrian and Lower Ordovician, except for the Hector shale, which is in places very much distorted. It is very

likely that Triassic, Jurassic, and Lower Cretaceous strata once existed here, and have been removed by erosion.

This section should probably be supplemented by the addition of a considerable thickness of Cambrian. The incompetent strata are the Mesozoic shales and sandstones and the shaly limestone and shale of the Banff.

TABLE III

COMPOSITE SECTION IN THE REGION OF BANFF—AFTER WARREN AND DOWLING

		Feet
Kootenay sandstone and shale	Lower Cretaceous	4,350
Fernie shale	Jurassic	1,600
Spray River limestone and shale	Triassic	3,400
Rocky Mountain quartzite	Pennsylvanian	698
Rundle limestone	Mississippian	2,431
Banff shaly limestone	Mississippian	1,408
Minnewanka dolomite	Devonian	3,318
		17,205

The incompetent beds are the Mesozoic formations and the shaly limestone of the Banff.

BRIEF OUTLINE OF THE HISTORY OF THE REGION

Schofield and Walker have shown that there was an uplift of the area involved in the Pre-Cambrian geosyncline late in Beltian time. This resulted in the erosion of some of the Beltian strata which had been deposited in that part of the area which was west of the present Rocky Mountain trench, and the deposition of conglomerates and shales northeast of what appears to have been a great geanticlinal mountain system. This inaugurated the geosyncline in which the strata now involved in the Rocky Mountains were deposited. The youngest pre-Cambrian sediments, Toby conglomerate, Horsethief shale, Corral Creek sandstone, and Hector shale, were probably formed as non-marine clastics during the time of uplift.

This episode appears to have been followed by a period of sinking, with the invasion of marine waters and initiation of a relatively narrow geosyncline in Lower Cambrian times. The purity of the quartz

sand then deposited suggests that the late pre-Cambrian sands were at that time partially eroded and redeposited, the materials being supplied chiefly from the east and south rather than from the west. By mid-Cambrian times the shores appear to have become low on both sides of the inland sea, for almost nothing except limestone was formed. This condition persisted through Upper Cambrian and part

TABLE IV

COMPOSITE SECTION NEAR THE ROCKY MOUNTAIN FRONT*

		Feet
Edmonton sandstone and shale	Upper Cretaceous	Thickness not given
Bearpaw shale	Upper Cretaceous	650
Belly River sandstone	Upper Cretaceous	1,025
Pakowki (?) shale	Upper Cretaceous	250
Benton sandstone and shale	Upper Cretaceous	775
Blairmore sandstone	Lower Cretaceous	950
Kootenay sandstone	Lower Cretaceous	350
Fernie shale	Jurassic	250
Rocky Mountain quartzite	Pennsylvanian	562
Rundle limestone	Mississippian	2,573
Banff shaly limestone	Mississippian	1,677
Minnewanka dolomite	Devonian	2,680
Ghost River limestone	Upper Cambrian	285
Cathedral limestone	Middle Cambrian	1,122
Ptarmigan shale	Middle Cambrian	
Unnamed formation	Lower Cambrian	500+
		13,649+

*The Mesozoic is adapted from Cairns' report (*Geol. Surv. of Can. Mem. 61* [1914]) on the Moose Mountain area, east of the front, whereas the Paleozoic is from Shimer and Walcott.

of Lower Ordovician times, but with very shallow water, as evidenced by shaly limestone and intraformational conglomerate. During the later part of Lower Ordovician (Lèvis) time black shale was deposited west of calcareous deposits, indicating low-lying land at the east, some deepening of the syncline in the region of the trench, and a certain amount of uplift farther west. The history in mid-Ordovician times is still obscure, but shallow-water deposits pushed eastward during the Upper Ordovician. Conditions during mid-Silurian times appear to have been much as in the Lèvis interval. After this deposition the whole area seems to have emerged, al-

though it was not greatly uplifted. There is no record of deposition during the Upper Silurian or Lower Devonian, although there is some evidence of erosion at that time. This was probably not stream erosion, however, but is more suggestive of a marine planation, such as may have accompanied the resubmergence which took place in mid-Devonian times. The latter was a time of widespread submergence in Canada, with the formation of limestone which has later been partially, or in places completely, altered to dolomite. Similar conditions persisted through the Upper Devonian, but toward the end of that period black shales were deposited in the Banff and Minnewanka areas. The source of the clastic particles must have been toward the east. The western shore could not have been far from the present position of the Purcell Mountains at this time, however, since Upper Devonian shales and sandstones are known in that region.

During Mississippian times only limestone and dolomite were deposited, and over an area less extensive than that occupied by the Devonian sea. The shores both east and west of the syncline must have been low. The sea remained in the region during part at least of the Pennsylvanian, but if the Rocky Mountain quartzite be truly Pennsylvanian instead of Permian as was supposed before Warren's work, then the Pennsylvanian was a time of still further narrowing of the syncline and filling-up of the sea which had existed since mid-Devonian times.

The preponderance of evidence seems to indicate general emergence during the Permian, and the Mesozoic deposits are very different from those of the Paleozoic.

Summarizing for the Paleozoic, it appears that the region now occupied by the Purcell and Selkirk Mountains was probably a land most of the time from late pre-Cambrian until the Triassic. It was a land of low relief, however, and not entirely stable. In Upper Cambrian and Mississippian times it was probably flooded, but shows evidence of uplift in Middle Ordovician, late Silurian, and early Devonian times.

The syncline east of it was narrow during Lower Cambrian times, became wider during Middle and Upper Cambrian, then having a width somewhat exceeding that of the present Rocky Mountains.

It contracted during the Ordovician and Silurian, became entirely emergent, and then suffered wide submergence, the mid-Devonian sea probably having extended to the Canadian shield. During the remainder of the Paleozoic there was progressive westward movement of the eastern strand. As a result of these movements the greatest thickness of strata was deposited in the region extending from the trench to Lake Louise, the Paleozoic sediments with the exception of the Devonian and Carboniferous, all thinning toward the east.

The Triassic was a time of deposition of muddy limestone and shale. The deposits as now known are thickest about Banff and thin rapidly eastward. Lower Triassic faunas predominate, but deposition probably continued until late in the period. It was probably a time when the geosyncline was coextensive with the present Selkirk, Purcell, and Rocky Mountain ranges, with higher land at the west than at the east. Conditions were much the same during Jurassic, Lower, Middle, and Upper Jurassic faunas now being recognized, but much of detail is yet to be ascertained. There can be no doubt, however, of an uplift which affected the Selkirk and Purcell Mountains in late Jurassic and early Cretaceous times. This uplift brought the whole area under consideration out of water during the deposition of the Lower Cretaceous (Kootenay) sediments. The Kootenay sediments thin rapidly east from the region of Banff, but their westward extent is unknown. The absence of coarse deposits from this region suggests that it was some distance from the Jurassic Mountains. During the Middle Cretaceous a part at least of the Kootenay sediments were below sea level and another great submergence, like that of the Devonian, affected Central Canada. The thickest section of the Cretaceous is in the eastern part of the Rockies in the Crowsnest section further south. It is probable that the same amount of sinking took place in the region at least as far west as Banff. Consequently, it appears that the deepest part of the Mesozoic geosynclinal prism is somewhat east of the deepest part of that of the Paleozoic. If, then, a profile be drawn along the top of the pre-Cambrian from the Purcell Mountains to Calgary, reconstructing that surface as it appeared at the end of the Mesozoic, two depressions would appear, one west of Lake Louise and one in the

region of Banff. This condition may have something to do with the structures which were formed when orogenic movement took place.

Sinking was not continuous throughout Middle and Upper Cretaceous times, but was interrupted by brief emergences. Each resubmergence was of less extent than the former, indicating a beginning of general uplift during late Cretaceous at least, and a filling-up of the depression with sediments shed from the rising Rockies. Even the latest Cretaceous deposits, the Edmonton, although dominantly terrestrial, show occasional invasion of marine waters. At the end of the Cretaceous, however, the emergence was general, and the region now occupied by the Rockies was considerably uplifted. This uplift was probably at first in the form of a great arch, the Paskapoo, which is usually regarded as Eocene in age, representing the sediments shed at this time. The later history is obscure, and can probably be revealed only through physiographic studies. The Paskapoo was involved in the folding and faulting. Later dated sediments are lacking close to the mountains.

STRUCTURE IN THE FOOTHILLS

Bordering the Rocky Mountains on the east is a region of hills and mountains known to the Canadian geologists as the foothill belt. The rocks in this area were disturbed at the same time as those in the Rocky Mountains proper, hence this region must be included in an account of the structure. Coal-bearing formations occur at many places throughout this belt, which has been studied by several members of the Canadian Survey. The region nearest the present section on which a report has been published is the Moose Mountain area, mapped by D. D. Cairns.[1]

MOOSE MOUNTAIN FOLD AND THRUST

The Rocky Mountain structure is first observed a few miles west of Calgary, where the Cretaceous and Tertiary strata show numerous anticlines and synclines. Just at the eastern side of Moose Mountain, $7\frac{1}{2}$ miles east of the Rocky Mountain front, the most eastern overturned fold is encountered. Northwest and southeast of Moose Mountain the fold is broken, becoming a thrust fault. These

[1] *Geol. Surv. of Can., Mem. 61* (1914).

structures bring the Mississippian limestone up as an island in the Blairmore (Lower Cretaceous) sandstone. The throw is at most about 3,000 feet.

FORGET-ME-NOT THRUST

When followed down the back slope the ascending series brings one to another and somewhat greater thrust in which the Mississippian is pushed over the Blairmore on the eastern margin of Forget-Me-Not Ridge, with a throw of about 4,000 feet. This is about 4 miles west of the Moose Mountain fault and $3\frac{1}{2}$ miles from the Rocky Mountain front. When traced a few miles northwest or southeast, this fault dies out in folds.

STRUCTURE IN THE ROCKY MOUNTAINS BELT OF OVERTHRUST BLOCKS

The eastern part of the Rocky Mountains from the Oldman River on the southeast to the Peace on the northwest constitutes a series of narrow parallel blocks, all consisting of strata which dip southwestward, and all thrust over one another to the northeastward. In the region under discussion the grain of the country strikes about N. 45° W., the dip is in many instances from 30° to 50°, and the thrust surfaces appear to be steep, sloping to the southwest at about the same angle as the dip.

FRONTAL THRUST

The thrust at the Rocky Mountain front is well exposed at Kananaskis, where the Bow River issues from the mountains. At this locality the Middle Cambrian rests on the Cretaceous, the throw is about 10,000 feet, and the plane of the thrust approximately horizontal for about $\frac{1}{2}$ mile. The best exposure, however, is the classic one described by McConnell[1] along the South Fork of the Ghost River, about 15 miles north of Kananaskis. Here, at the actual front, the upper part of the Middle Cambrian rests on the Benton, indicating a throw of about 10,000 feet. Two miles up the South Fork, however, the Lower Cambrian rests upon approximately the same strata, increasing the throw to about 11,500 feet. The overriding here is at least 2 miles. The length of this fault is un-

[1] *Geol. Surv. of Can. Ann. Rept.*, Vol. II (1887).

known, as it has not been traced very far north of Ghost River. It extends at least 50 miles southeastward.

MINNEWANKA THRUST

The section here presented extends through Devils Gap, south of Lake Minnewanka, just north of Banff, and westward to the Bow River at Hole-in-the-Wall. Going westward from Devils Gap, a zone of faulting is encountered about 2 miles from the frontal escarpment. At least two small thrusts can be detected here. They are, however, of no great importance and merely delay the westward disappearance of the strata. They are probably connected with the small anticline on the south fork of the Ghost.

About a mile west of the eastern end of Lake Minnewanka there is a more important break. The Rundle limestone here overrides the lower part of the Triassic Spray River shale on a plane making about 45° with the horizontal. At the west of the main thrust there are two or three subsidiary ones, in which slices of the Rundle have slid on one another. The throw here is about 2,500 feet. This fault has been traced southward in the Fairholme Mountains but appears not to reach the Bow Valley. According to McConnell, it has a greater throw farther north. West of this fault there is a very sharp syncline and then an anticline. The latter is partially dissected and cut obliquely by the valley of the lake, producing puzzling structural features.

INGLISMALDIE THRUST

The next fault, the Inglismaldie thrust, is only 2½ miles west of the one just described. It cuts through the mountains just east of the peaks of Perchee and Inglismaldie, crosses about the middle of Lake Minnewanka, and produces the cliffs on the eastern side of the Palliser range at the north. At this particular locality the Minnewanka limestone rests on the Spray River shale, the throw being about 6,000 feet. Dowling mapped this fault in detail, and found that it disappeared in a fold in the southern part of the Fairholme Mountains, about 3 miles north of the Bow Valley. At the north its throw increases, so that the Minnewanka overrides the Kootenay about 18 miles north of Lake Minnewanka. North and south of Panther Creek it has a throw of about 15,000 feet.

STANDLEY THRUST

The next fault to the westward crosses the western end of Lake Minnewanka just east of its outlet. It is there entirely within the Rundle, and has a throw of only a few hundred feet. Farther north, however, it carries the Rundle over the Spray River shale. It can be traced northward for about 10 miles, but southward for only a mile or two.

CASCADE THRUST

Just east of Banff, along the base of Mount Rundle and on the lower slopes of Cascade Mountain, is another important thrust. Dowling mapped this fault in detail, showing that the greatest dislocation was west of Canmore, where for a distance of a mile along the strike Cambrian strata override the Kootenay, with a throw of nearly 17,000 feet. Along the foot of Rundle the Devonian rests on the Kootenay, with a throw of 15,000 feet. The same is true at the southern end of Cascade, but farther northwest the throw decreases until the fault dies out in an anticline. Some consider this fault the northern extension of the Lewis thrust, but there is as yet no published evidence which appears to warrant that assumption.

SULPHUR THRUST

The next block is a narrow one, for at Banff another thrust is encountered. It extends along the eastern foot of Sulphur Mountain, crosses the Vermilion Lakes about half a mile west of the railroad station at Banff, and is well shown on the shoulder of Norquay, where the Minnewanka overlies the Spray River shale. Back of the Banff Springs Hotel the quartzite at the base of the Devonian rests upon the upper part of the Triassic with a throw of 10,000 feet. This fault has not been traced very far northwest or southeast. Just west of it there is some subsidiary faulting which brings up a wedge of Rundle between the Minnewanka and Spray River near the road.

EDITH THRUST

West of Sulphur Mountain is another thrust which, north of the Bow, is responsible for the needle-like spine of Mount Edith and other peaks northwest of it. Just north of the road, $3\frac{1}{2}$ miles west of Banff, the Minnewanka is seen to override the lower part of the

Spray River on this fault, with a throw of about 6,000 feet. This fault has not been traced very far in either direction.

SAWBACK THRUST

A mile west of the Edith thrust the Upper Cambrian is thrust on the Devonian in the core of a broken anticline where the Sawback Range dies out at the Bow Valley. The structural relationships here are not easily deciphered, but the thrust appears to be only a small one with a throw not exceeding 1,000 feet.

JOHNSTON THRUST

Seven miles west of Banff the Bow ceases to be a transverse valley. From that point northwestward it is approximately, although not entirely, parallel to the strike throughout its upper reaches. If a section be made across the Bow, from Hole-in-the-Wall Mountain at the southern end of the Sawback Range to Pilot Mountain, it will be found to represent a simple syncline with steeper dips on the eastern than on the western limb. If this syncline be followed northwestward, along Johnston Creek, it will be found to change within 5 or 6 miles into a thrust with increasingly great throw. East of Castle Mountain this fault brings the upper part of the pre-Cambrian over the Mississippian, a throw of about 18,000 feet. Farther northwest, at Fossil Mountain, the displacement is perhaps a thousand feet greater, as older pre-Cambrian beds are thrust on the Devonian.

SUMMARY ON THE BELT OF THRUST BLOCKS

The Johnston fault marks the western boundary of the eastern portion of the Rockies, the region of thrusts. Eleven more or less notable breaks are encountered in passing about 35 miles across the strike. Six of these would, in most regions, be called major thrusts as they have displacements of 6,000 feet or over. All but two show a throw of more than 1,000 feet. The least important of them has been traced at least 10 miles along the strike; others are known to extend for at least 50 or 60 miles, probably much farther. Yet as thrusts they are not really important, for there appears to have been comparatively little overriding. Eight of the thrusts, including such important ones as the Cascade and the Johnston, have been found to

die out in folds at one or both ends. All except the Frontal are so steep that there is little suggestion that one block has ridden far over another. If they had done so, eastwardly bowed arcs in the traces of the faults would have been produced. These do not exist. This is, therefore, not a real *schuppen* structure, but one very commonly seen in slates, in which breaks a few inches long are developed, with real reverse faults which die out in low folds at either end. These appear to be the result of compression in two directions.

GENTLY FOLDED BELT

West of the Sawbacks, extending as far as the Van Horne Range, a distance across the strike of about 25 miles, is a region of anticlines and synclines with low dips and occasional gravity faults. The first of these folds is the Castle syncline. As already stated, this syncline is a valley where crossed by the Bow before it breaks through the Sawback-Borgeau Range, but northwestward Castle Mountain is in its center. Still farther northwest it may be beautifully seen beneath Mount Richardson and Ptarmigan Peak by any geologist who cares to climb Mount St. Piran or any of the other peaks about Lake Louise. Southwest of it is the Bow anticline, which is really a great dome with its highest point in Mount Obrian directly north of the station at Lake Louise. So far as this section across the mountains is concerned, this is the summit of the Rocky Mountain geanticline. The basal Lower Cambrian would, if it had not been denuded from Obrian, have been there about 10,000 feet above sea level. This indicates a minimum of 30,000 feet as the amount of uplift in this dome since the surface was practically at sea level in late Cretaceous times.

The structure in the Hector shales is interesting and somewhat puzzling. On Obrian and in the Bow Valley west of the station at Lake Louise the shale is very much disturbed, showing many sharply folded anticlines, synclines, and faults. Yet wherever it is seen in contact beneath the Lower Cambrian quartzites it is evenly bedded, and so nearly conformable that a discordance has been seen at only one locality, on Bath Creek. The disturbance probably is not due to pre-Cambrian folding, but to the well-known creep which occurs when soft rocks are involved in folds between massive ones. Still

another explanation may be suggested; namely, that it may be due to the pressure of the superimposed massive beds in the mountains which surround the pre-Cambrian area.

Southwest of the Bow anticline is the Bosworth syncline, which is now followed in part by the Great Divide. Along it are such well-known peaks as Mounts Whyte and Victoria, back of Lake Louise. In the axis of the syncline is the Sherbrook fault, marked by Sherbrook Lake and the O'Hara Valley. It is a small gravity fault with downthrow at the west which steepens the dip of the western limb of the syncline. Southwest of this is the Yoho anticline broken by the Stephen-Cathedral fault of Allan, which follows the axis of the scenic Yoho Valley and separates Cathedral Crags from Mount Stephen. The downthrow is on the western side of this fault, and amounts to over 3,000 feet.

On the western side of Mount Stephen there is the Stephen-Dennis fault of Allan, which brings the soft, shaly Upper Cambrian against the more massive Middle Cambrian. This continues northwestward through Burgess Pass, west of Wapta, and through the Presidential Range. We have supposed this to be a gravity fault, letting down the southwestern side, but there is some suggestion that it is really a thrust toward the east. It deserves further study.

Southwest of this is the wide Otter Creek syncline, extending to the Van Horne Range and floored with soft calcareous shales of Upper Cambrian age. They have suffered severe compression and are partially metamorphosed, showing minor disturbances not indicated on the diagram.

WESTERN BELT OF THRUSTS

In the Van Horne Range the first of a series of easterly dipping overthrusts is reached. Between the Van Horne Range and summits of the Dog Tooth Mountains west of the Trench there is a belt of territory 15–20 miles wide in which the dips are prevailingly toward the east, generally very steep. The strata have been tightly folded, somewhat overturned toward the west. There are several thrusts, the planes of which dip steeply eastward. This region includes the western part of the Van Horne Range, the Beaverfoot and Briscoe ranges, the Rocky Mountain trench, and the eastern flanks of the

Dog Tooth Mountains. The geological structure is complicated, but admirable sections have been worked out by Allan south of the canyon of the Kicking Horse and by Walker in the Windermere area. At least four principal thrusts are shown, but no one of them has a very great throw. All of the rocks seen east of the trench are Upper Cambrian, Lower, Middle, and Upper Ordovician, and Silurian: west of it there is some Lower Cambrian, some Upper Cambrian, and in the Windermere district some Devonian. All these formations, with the exception of the Upper Ordovician quartzite and dolomite, are prevailingly thinly bedded, shaly, and weak. Since the authors have done no original work in this area it will not be described in detail. The section shown is adapted from the work of Allan, with some modification resulting from the investigations of Walker, Walcott, and Shepard.

STRUCTURAL GEOLOGY OF NORTHEASTERN OKLAHOMA

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ABSTRACT

Detailed comparative studies of the structure of northeastern Oklahoma at the surface and underground have shown that beneath gently tilted and slightly folded rocks at the surface there are more complex structural features, largely more steeply folded and more or less truncated buried anticlines, which have permitted the accumulation and concentration of oil and gas. This folding is different from that in mountain chains and is called the "*Plains type of folding.*" It is characterized by "*buried hills.*"

INTRODUCTION

Geologic structure is observed at the surface and interpreted underground from surface exposures, mine workings, and well logs. Geologic history is determined likewise from surface and underground observations and well logs. All the rock exposures within that part of Oklahoma which might produce oil have been accurately mapped and the surface structure determined. Over 100,000 wells have been drilled for oil in Oklahoma, and the well logs and cuttings have yielded stratigraphic and structural data from which the earlier, buried geologic history has been interpreted.

Besides deciphering scientific facts these studies of subsurface data have given the oil producers the practical information necessary for the discovery of new oil fields and for proper testing and development of the various oil and gas horizons.

Scientific research is the study of scientific facts. Research concerning the detailed structure and stratigraphy of Oklahoma's oil fields has proved so profitable to the oil producers that scientific research by petroleum geologists, technologists, geophysicists, and chemists is increasing each year. Co-operation by the oil companies toward the advancement of scientific research has permitted the publication by the American Association of Petroleum Geologists of a symposium entitled, *Structure of Typical American Oilfields*, two volumes of which have already been published.

A need for clarification of fundamental principles and processes

arises from time to time. A restatement of the structural history of northeastern Oklahoma, east of the Nemaha Mountains (Granite Ridge of Kansas) and not including the Arbuckle Mountains or Seminole Uplift, is reproduced below as revised from a paper by the writer entitled "Structural Geology of the Mid-Continent Region" and published in the *Bulletin of the Geological Society of America* for 1925. A very valuable discussion of fundamental principles will be found in *Structure of Typical American Oilfields*, Volume II, by F. G. Clapp.

DEFINITION

It is important to understand that structures at the surface and underground in Oklahoma are different; different in most places in degree. The terms "disconformity" and "unconformity" are carefully distinguished, the former referring to a hiatus, the latter to a discordance which is, at least locally, angular. "Buried structure" beneath unconformities has become of paramount importance because the correlation of well logs leads to prediction of structure as drilling proceeds and also in advance of drilling. Structure can rarely be mapped satisfactorily at the surface in the area of present exploration although surface mapping has led to the discovery of many oil fields. Buried structure is a general term which in Oklahoma has acquired the meaning "buried *anticlinal* structure."

It was pointed out by the writer in 1917 that the Healdton oil field was underlain by a buried hill of Ordovician limestone, the structure of which is not known even today. "Buried hill" is a general term meaning a buried physiographic feature and not specifying the composition or structure of the rock comprising the hill. Topographic hills and ridges may or may not be structural, and buried hills are not by definition anticlinal. Buried hills which are now exposed by erosion are called "resurrected hills," or "baraboos" (Fig. 1).

The existence of buried hills and ridges and mountain chains has been in many parts of the world the determining factor in the location of anticlines and consequently of oil fields in the overlying strata. Oil may be concentrated at the unconformable surface of the hills because of the existence of buried topography together with a

reservoir. It may also be found in the buried hills themselves, whether anticlinal or homoclinal, where its presence has no relation to the buried topography.

STRATIGRAPHY

The stratigraphy of northern Oklahoma is sufficiently well known that it need not be discussed. A brief review of oil-producing horizons is given to clarify relationships described later.

The youngest producing horizon is of Permian age and the shallow sands discovered in the Garber field in 1917 were the only ones of economic importance. The Permian formations underlie the western half of the state only.

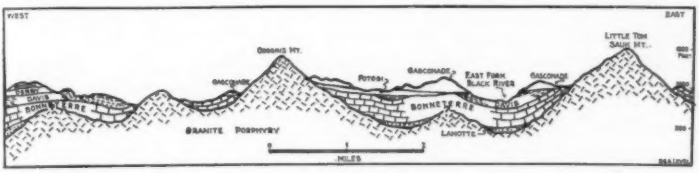

FIG. 1.—Cross-section of part of the St. Francis Mountains, southeastern Missouri, showing resurrected hills of granite porphyry overlain by sedimentary rocks of Cambrian and Ordovician ages which were deposited between the old porphyry peaks. The dips in the sedimentary rocks have been described as initial. (After C. L. Dake, Geologic map of the Potosi-Edgehill quadrangles, Missouri Bureau of Geology and Mines, 1929.)

Oil was first discovered in northeastern Oklahoma in sands of Pennsylvanian age. The Bartlesville sand with its equivalents, the Glenn sand and Burbank sand, is the best known. The Dutcher sand occurs at the base of the Pennsylvanian section west and southwest of Tulsa. The Cromwell sand of the Cromwell oil field is near or at the base of the Pennsylvanian section.

The "Mississippi lime," thought until about 1916 to be the deepest possible producing horizon in the state, is now known to gradually disappear south and southwest of Tulsa and to be overlapped by the so-called Mayes and overlying Caney shale. The Chattanooga shale is the best-known Mississippian formation and lies at or close to the base of the section. The Misener sand is a sand found locally at Seminole and elsewhere on the pre-Chattanooga erosional surface and is the only important oil sand of this age.

Oil was found in the Hunton limestone group of Siluro-Devonian age in the Beebe oil field in 1923 and it is one of the important oil horizons at Seminole.

Asphalt was mined in the Simpson formation, of Ordovician age, in the Arbuckle Mountains many years ago, but this formation was not recognized underground or as an oil horizon until 1916. Developments southwest of Glenn Pool during 1918–19 showed the presence of a number of small, prolific oil fields in the "Wilcox" sand which was proved later to be equivalent to part of the Simpson formation. Deeper drilling in the Tonkawa field in 1924 proved that this sand might occur on larger anticlines and led to the intensive search for oil in the Ordovician in the sand series of which the "Wilcox" is a member and in the upper eroded surface or in the upper part of the Arbuckle limestone, commonly called the "Siliceous lime." At Oklahoma City oil is found 200–600 feet below the eroded surface or, stratigraphically, 500–800 feet in this limestone, as well as in the Simpson formation.

Deeper oil horizons may be found in the Arbuckle limestone. The prospect for oil in the underlying Reagan sandstone or its equivalents is untested because this formation is missing from the buried hills of basement granite in the northern part of the state. The Reagan rests on granite.

The significant features of the stratigraphic section are the small total thickness of the northern Oklahoma sedimentary section as contrasted with geosynclinal areas such as the Ouachita Mountains, and the small individual thicknesses of formation such as the Chattanooga shale or of groups of formations between disconformities and unconformities, regardless of their widespread distribution.

STRUCTURE—PLAINS TYPE OF FOLDING

Anticlines and folds of anticlinal type, the most common of which is the nose, form the dominant type of structure in the strata exposed at the surface in northern Oklahoma. In the eastern portion of the area under consideration and especially in eastern Osage County, both anticlines and noses are found at the surface. Farther south and west, and consequently higher in the stratigraphic section, surface anticlines are very scarce and noses are found in their stead. A structure contour map on any single horizon will show folds of

approximately the same relief from east to west and from northeast and southwest irrespective of depth of burial.

The distribution of anticlines is irregular. They rise as isolated folds and groups of folds from a gently warped and tilted surface and they appear to have been elevated from this surface rather than to stand as relics of a former level from which the general surface and intervening synclines have been downwarped.

Underground correlations indicate a possible division of surface anticlines into normal, reflected, and surficial types, the first being parallel folds, the second rejuvenated anticlines, and the third anticlines which disappear in depth.

Normal anticlines are rare in northeastern Oklahoma. In practically all anticlines which have been drilled there is some thinning in the section above the anticline as contrasted with the thickness under the adjacent normal dip or in adjacent synclines.

Surficial folds are rare. They disappear downward gradually, usually in the Pennsylvanian section. They are of late Pennsylvanian or Permian generation. It is probable that the sharp anticlines northeast of the Healdton and Hewitt fields, southern Oklahoma, are of this type.

Reflected folds increase in steepness downward through the Pennsylvanian, and especially beneath each unconformity or disconformity (Fig. 2). Contrary to the usual conditions that folding is limited to periods of major uplift and erosion, the effect of progressive rhythmic or spasmodic folding and re-elevation, is noted throughout the section. This cannot be explained by shearing or squeezing or flowage of beds on folds, because the folds are not sufficiently steep. It may be due in part to relative condensation of sediments, yet comparison of sections along the Nemaha Mountains on strong anticlines and in adjacent synclines shows that in them thinning is not confined to shale, but occurs in sandstone sections which cannot be compacted in appreciable amount. Few, if any, examples can be found in northeastern Oklahoma of anticlines formed by compaction of shales above buried homoclinal hills of "Mississippi lime" or above convex sand lenses where the underlying rocks are not anticlinal. Some of the shoestring sands in Kansas are, however, underlain by homoclines and overlain by anticlines.

Most of the folds in the Tulsa area, between Claremore, Pawhuska, Sapulpa, and Henryetta, are small and low. The average area inclosed within the lowest closing structure contour does not exceed a square mile (Fig. 3). Some of the anticlines, both at the surface and underground, are from two to three miles long. The largest folds, such as Cushing, consist of groups of smaller anticlines and domes and are on lines of fracture and folding as described below.

Closure is defined as the amount of structural relief between the highest point and the lowest closing contour on an anticline. The

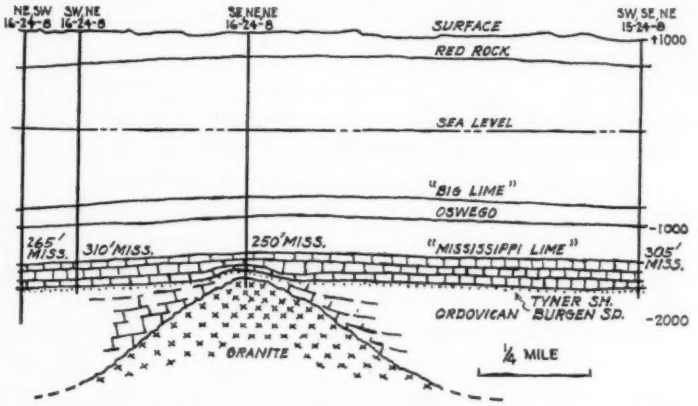

FIG. 2.—Cross-section of a small anticline in sections 15 and 16, T. 24 N., R. 8 E., Osage County, Oklahoma. The topography of the buried hill of granite is reflected in the overlying sediments of Ordovician, Mississippian, and Pennsylvanian ages, but the anticline becomes more gentle in the upper beds. The amount of east (reversal) and west dip from the center well to the farthest well shown on either side is as follows: Top "Big lime" 83 feet W., 78 feet E.; top "Mississippi lime" 138 feet W., 101 feet E.

amount in anticlines near Tulsa in the Pennsylvanian is commonly 5 to 30 feet; in some it is as much as 90 feet; that in the Mississippian and Ordovician varies from 100 to 200 feet.[1] Along the Nemaha Mountains the Mississippian rocks are truncated on most of the anticlines, and yet in northeastern Oklahoma and at Seminole they are approximately conformable to the older rocks. The amount of

[1] The illustrations, Figs. 2 and 3, are selected from among the most pronounced anticlines under which wells have penetrated granite, because a smaller amount of reverse dip could not be shown in a cross section.

closure is frequently proportional to the size of the anticline. It is definitely known that still greater relief occurs on the surface of the underlying basement granite, as at Cushing, Spavinaw (Fig. 4), and Eldorado, Kansas, and under many small anticlines.

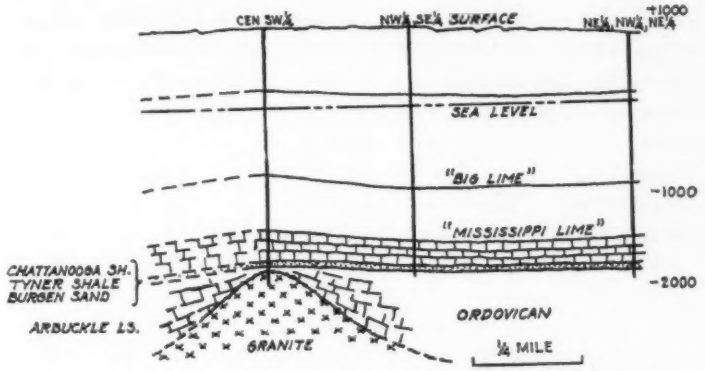

FIG. 3.—An anticline in Section 9, T. 21 N., R. 9 E., Osage County, Oklahoma, overlying a buried granite hill. The amount of east dip (reversal) in approximately one-quarter mile is as follows: Upper limestone, 40 feet; "Big lime," 90 feet; top "Mississippi lime," 100 feet.

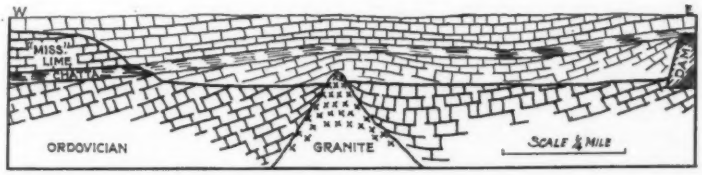

FIG. 4.—Cross-section of the Spavinaw resurrected hill, in Spavinaw Creek, Mayes County, eastern Oklahoma, one-half mile west of the Spavinaw dam. The unroofed granite peak is surrounded by gently tilted, silicified limestone of Ordovician age (Cotter formation) overlain unconformably on the south side of the creek by Chattanooga shale (Mississippian) and "Mississippi lime." The granite peak is reflected as an anticline in the overlying rocks because of at least two periods of uplift after their deposition. Many, if not most, of the anticlines in northeastern Oklahoma are underlain by similar buried hills.

The abundance of anticlinal folds east of the Nemaha Mountains —with the exception of Cushing—is inversely proportional to size.

Most of them are irregularly disposed, without system, both on the surface and underground, but some are alined and are connected underground by structural saddles to form ridges. There is a definite concentration of anticlines in the Tulsa area. The axial trend of about 85 per cent of them is northeast.

All of the folds are superposed on a homoclinal westerly dip, both at the surface and underground, which varies from 30 to 90 feet to the mile. In the few townships in which there are adequate outcrops, and in which no noses can be mapped at the surface, anticlinal folds may occur in the deeply buried sediments. As a rule the apex of anticlines in the Ordovician rocks is slightly west of that at the surface and the east dip is steeper than the west dip in the older rocks. South and southwest of Tulsa the Pennsylvanian rocks were warped several times in different directions, causing notable convergences in certain formations.

Stratigraphic sections measured from the same bed at the surface to formations underground show thinning on anticlines in strata of Pennsylvanian age, but little in those of pre-Pennsylvanian age except in case of pronounced unconformities such as occur on the Nemaha Mountains and at Cushing. Part, but not all the thinning is due to convergence. Most of it is due to upfolding of the anticlines.

On small anticlines north of Tulsa thinning in the section (Figs. 2, 3) between the "Mississippi lime" and "Oswego" (Fort Scott) limestone is found in some anticlines only; about 10–30 feet in 400–800 feet of shale, or 1–7 per cent. Between the Oswego and the top of the "Big lime," in an interval of 200 feet, there is no thinning. Between the "Big lime" and Layton sand, an interval of 900 feet of shale, there is usually thinning of from 20 to 100 feet, or 2–10 per cent. Correlations of formations between the Layton sand and surface beds are unsatisfactory, but the total interval may show a change in structure of as much as 50 feet in a section of 1,100 feet, or 5 per cent, part of which is due to westward shift of the top of the anticline.

In the Okmulgee area (Fig. 6) an older Pennsylvanian section appears and thickens east and south. Between the "Mississippi lime" and the top of the Dutcher sand, where the interval is 200 feet, there is little thinning. Between the Dutcher and top of the

Glenn sand, a sandy section of 500–700 feet, there may be thinning of 50 to 150 feet, or 7–12 per cent, in comparison with wells one-half mile on either side of the apex of the anticline.

Southeast of Okmulgee, near Warner, in section 33, T. 11 N., R. 19 E., there is a conspicuous unconformity between a truncated fault-fold in the McAlester formation and gently tilted, but not folded Savanna sandstone. This unconformity proves that both folding and faulting (the faults of the southwest end of the Ozark uplift) took place in pre-Savanna time. This movement induced so

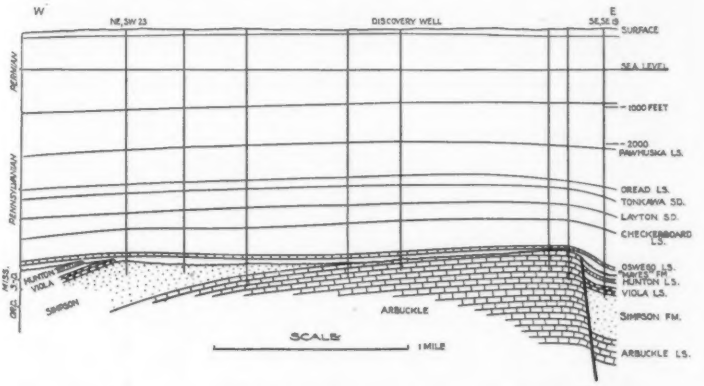

FIG. 5.—Cross-section of the Oklahoma City oil field, one of the largest truncated and rejuvenated anticlines along the Nemaha Mountains. A typical fault of post-Mississippian, pre-Pennsylvanian age, has been found on the east side of the buried anticlinal hill of older rocks.

much warping that measurements of intervals above the Glenn sand in the Okmulgee area are unsatisfactory.

Faulting is known to have occurred later in the Pennsylvanian—the rows of echelon faults which trend north-northeast. The throw of over 80 per cent of these individual faults is less than 30 feet.

The Nemaha Mountains are a system of anticlinal folds subsequently or contemporaneously fractured to form a broadly tilted fault block, bounded on the east by a continental fracture, 450 miles long with a displacement up on the west of 500–1,500 feet (Fig. 5). The anticlines connected with the Nemaha Mountains were formed

first, making it primarily a line of folding, but the normal faulting is now the major structural feature. A number of minor, parallel or echelon fold-fractures are thought to exist west of the Nemahas. The Cushing anticline is the largest uplift on a similar, minor fracture east of them. Little is known of north and south limits of the Nemahas and of the fractures farther west, but it is obvious that the main fracture system separates a region on the east of small,

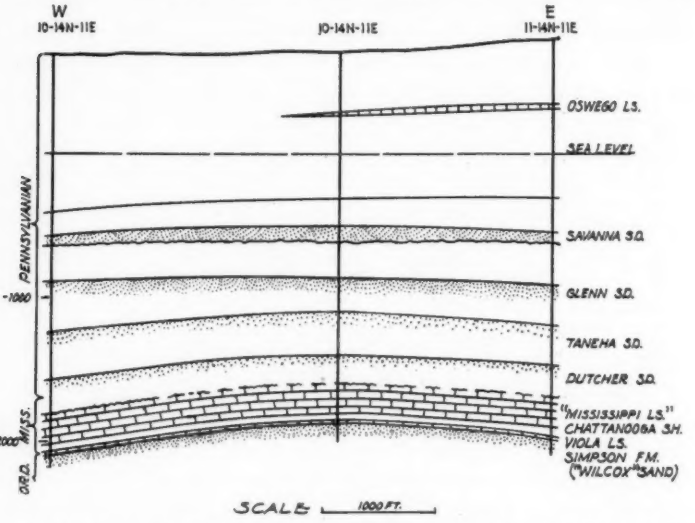

FIG. 6.—Cross-section of a small anticline in sections 10 and 11, T. 14 N., R. 11 E., near Okmulgee, Oklahoma. The field was located on a surface nose, but subsurface reversal (east dip) is not evident from these well logs above the Glenn sand. The reversal is 30 feet on the top, 60 feet on the bottom of the Glenn sand, the same on the top of the Dutcher sand, 70 feet on the top of the "Mississippi lime," and 70 feet on the producing "Wilcox" sand of the Simpson formation.

rounded anticlines from a region on the west of both large and small lineal anticlines bounded by long, parallel fractures.

Detailed examination of these fractures shows one or more series of echelon, steeply folded and faulted anticlines along the main echelon fault line or lines with more gently folded, unfaulted anticlines west of the faulted ones. A similar condition of large and small folds is found on and west of the Cushing line of anticlinal folding.

Truncation of these fault blocks and anticlines left low, buried anticlinal hills with topographic relief of from 50 feet to over 200 feet, but most of this relief was on the east side of the fault lines.

STRUCTURAL HISTORY

A description of structural history must commence with the pre-Ordovician basement, on the original configuration of which the overlying structure depends. The basement crystalline rocks are exposed in the St. Francis Mountains of Missouri, and the Arbuckle and Wichita Mountains. The topography when the Cambro-Ordovician sediments were deposited near Tulsa can be reconstructed from a study of logs of the few wells that have penetrated it and from analogy to a region where these rocks are now exposed.

This surface was a peneplain of low relief with small rounded hills, some small sharp monadnocks, and some major low ridges of crystalline rocks. Surface configuration was controlled by relative resistance of rocks to weathering. Physiographic relief would also be produced by the erosion of mountain chains, fault zones, and major joint blocks. Monadnocks might have been developed in certain types of igneous rocks rather than in metamorphic rocks and might have been most abundant over certain batholithic or otherwise localized areas of rocks of these types. Continental grain may have been of importance, the "knots" in the grain representing the larger units, but the grain is supposed to have trended northwest, whereas the only suggested alinement of buried granite hills is east of north.

A geological map of southern Missouri shows widespread distribution of Mississippian and Cambro-Ordovician limestones with distinct groups of resurrected porphyry hills in only two areas in the St. Francis Mountains, near Eminence and Ironton (Fig. 1). The uncovered hills are known to have been very slightly eroded since re-exposure and have been found by drilling to have stood as submarine islands 500–1,000 feet high in the Cambrian sea. East of Ironton a broad exposure of granite shows a flat surface without similar hills.

Ordovician rocks were deposited over Oklahoma under rather uniform conditions of sedimentation, and drilling has shown little evidence of the regional or local unconformities which are known in

Kansas. Deeper drilling indicates a widespread disconformity or unconformity at the top of the Arbuckle limestone. Development of the Oklahoma City field has shown the possibility of a local unconformity which, if present, dates the initiation of folding along the Nemaha Mountains as far back as Ordovician time.

The thickness of Ordovician rocks north of Tulsa is 800–1,000 feet and a few granite hills are found nearby in the Hominy sand of Ordovician age.

Siluro-Devonian limestones, usually called the Hunton group, were deposited disconformably on the Sylvan shale, of Ordovician age. Both transgressive and regressive overlaps seem to be recorded in these limestones.

Uplift, westward tilting, and slight local folding followed by base-leveling preceded Mississippian sedimentation. All the older rocks down to the middle of the Arbuckle limestone were truncated in progression northeastward. This is the most profound Paleozoic unconformity in northern Oklahoma. Little is known concerning the amount of local anticlinal folding in northern Oklahoma, but a few examples of such movements are thought to exist and to have been preserved from later erosion. In the Seminole district larger folds were developed and from them the Hunton rocks were removed. Likewise, little is known of the details of topography on the base-leveled surface except at Seminole where small hills covering about a square mile, with a maximum relief of 300–500 feet, have been revealed by drilling. These buried hills are not anticlinal.

Chattanooga shale, with an average thickness of about 30–50 feet, rests on the base leveled surface and is found almost everywhere where younger Pennsylvanian rocks are preserved. It is absent from the tops of a few small granite hills. The overlying "Mississippi lime" is widespread in northern Oklahoma, eastern Kansas, and western Missouri.

Renewed uplift and tilting upward in Missouri, and upward in the western half of Oklahoma, and downward in northeastern Oklahoma, preceded the deposition of the Cherokee formation, of Pennsylvanian age. This movement may have been subsequent to the deposition of the oldest Pennsylvanian rocks in the southeastern part of the State. The Nemaha Mountains, the Cushing anticline, and

other large anticlines and lines of anticlines were folded and truncated by erosion at this time. Most of the minor anticlines in the vicinity of Tulsa and Okmulgee were not folded at all at this time or were folded not over a few tens of feet. The amount and extent of local folding may be judged from subsurface data and from examination of the resurrected hills of "Mississippi lime" east of Claremore. The Ouachita, Arbuckle, and Wichita Mountains and Seminole Uplift were folded after the beginning of Pennsylvanian time, but not all contemporaneously.

During the Pennsylvanian period the locations of many of the anticlines in Oklahoma were determined or redetermined by differential movements which affected local areas at the same time. Uplift of the mountain masses on the south and of the Ozark Uplift on the east caused broad warping of the Pennsylvanian basin. Rotational stresses acting against the Nemaha Mountain fracture system of earlier generation created the lines of echelon faults which cut a limited Pennsylvanian stratigraphic section in a small geographical area.

Before the close of the Pennsylvanian the mountains on the south had been folded. After Permian sedimentation all the anticlines of northern Oklahoma were folded or refolded. Many owe their location to underlying buried granite hills, many to anticlines of earlier generation along the Nemaha Mountains, which, in turn, may date back to pre-Cambrian grain, structure or topography or to a combination of these factors. Some of the lines of folding were produced by compression parallel to or between older lines of folding or fracturing. In these folds there is very slight, progressive changes in stratigraphic thickness on and off the anticlines but no evidence of unconformities. Some of the small anticlines may have originated at this time, and obviously, the surficial folds are of this generation. Pennsylvanian faults may have determined the location of some of the anticlines.

INTERPRETATION OF STRUCTURE

The Plains type of folding consists at the surface of very small, low anticlines superposed on a gently-dipping homocline, and underground of small and large anticlines, large uplifts, depressions, or faults with little or no surface manifestation. In northern Oklahoma

underground anticlines occur singly, in irregular groups, in rows, and along lines of folding. The latter are, because of later normal faulting, at and near the edges of broad fault blocks bounded by fractures of great lineal extent, but with small vertical displacement. Almost all of this minutely complicated structure is concealed because of steeper dips in formations underground due to unconformities and because of stratigraphic convergences.

The amount of folding in stratigraphic sections with a total thickness of 2,500–10,000 feet ranges from about 5 to 10 per cent, where there is no pronounced unconformity, and from 10 to 30 per cent in the pre-Pennsylvanian, truncated rocks on anticlines along the Nemaha Mountains.

Well records show two major structural movements each followed by peneplanation, the first at the close of the Devonian period and the second at the close of the Mississippian period or early in the Pennsylvanian period. Broad anticlinal folding accompanied the first movement, both broad and local anticlinal folding and major fracturing accompanied the second. Local anticlinal folding and broad warping followed the second movement, gentle folding being continuous at times, rhythmic or spasmodic at other times until the middle of the Pennsylvanian period. Local anticlinal folding followed Permian sedimentation.

The drill has also shown that many small, local anticlines are underlain by buried hills of basement igneous rocks, all of which are called "granite." Also, some of the largest anticlines along tilted fracture blocks are underlain by "granite" hills. Some of these small but sharp hills had topographic relief of 800–1,000 feet, for they projected above the top of the Ordovician, which is normally of that thickness, and were finally covered by "Mississippi lime." "Granite" has not been found above its normal position under synclines.

Combining these facts with observations made in the resurrected porphyry hills of the St. Francis Mountains of Missouri the deduction is reached that there were areas and lines of granite (using the term loosely) hills in northern Oklahoma which were submerged by the Ordovician seas. The irregularly distributed groups of hills overlay areas of certain kinds of igneous rock which weathered into hills; the lines of hills overlay lines of continental grain.

Many, if not most of the anticlines in northern Oklahoma are thought to overlie buried granite hills.

During post-Mississippian folding most of the local anticlines were probably formed for the first time. They were formed, not by tangential compression of the thin veneer of sediments above a rigid basement, but by slight compression of the basement which was translated into vertical forces that created very gentle folding of the overlying sediments. Some of the buried hills acted as loci for the formation of anticlines at this time; the others served the same function in subsequent Pennsylvanian movements. Between the principal lines of folding other parallel lines were formed, some contemporaneously, some later.

In addition to this slight amount of folding, very long faults were developed on the east sides of lines of folding (faults on the west side are younger). The longest fracture bounds the Nemaha Mountains.

The origin of the anticlines and associated fractures is debatable. There was active compression along and over buried granite hills and other "knots" in the continental grain. Tangential forces were resolved into vertical forces. The fractures were formed either by a collapse of the regional tangential forces or (as pointed out to the writer by Stuart K. Clark) by tensional stresses along the crests of the anticlines and shearing stresses on the flanks which ultimately produced normal faulting as a result of the failure of the rocks along the plane of maximum shear.

In brief, the position of practically all of the anticlines in Oklahoma was determined early in Pennsylvanian time and the position of most of them was influenced by pre-Ordovician topography or grain. They cannot properly be called posthumous because the compressive forces that created them were active from time to time.[1] Once the location and shape of an anticline was determined, all subsequent structural movement in the geosynclinal prism of sediments tended to accentuate the anticlinal relief in the older rocks

[1] Posthumous folds, as recognized by Goodwin Austin and defined by Edward Suess, are those later folds which had a trend parallel or approximately parallel to a system of earlier folds. Each of the folds described above was folded recurrently and, in Pennsylvanian time, at short intervals so that they can scarcely be said to have "died" between times of folding.

because the relative degree of competence of the strata decreased upward.

Folding which terminated Paleozoic sedimentation in Oklahoma refolded the pre-existing anticlines making reflected anticlines. It created new anticlines between them, some being surficial and others normal parallel folds and lines of folds which can be distinguished from reflected anticlines because there are no unconformities with changes of rate of dip in the columnar section.

CONTEMPORANEOUS FOLDING AND OIL ACCUMULATION

Oil fields are genetically connected with this geologic history for petroleum-bearing strata accumulated in epeiric seas. Both generation and accumulation of oil are intimately connected with contemporaneous structural movements of slight magnitude within these seas which provided suitable environmental conditions for minute plant and animal life, created reservoirs, generated petroleum, and caused it to accumulate. Mid-continent oil fields are found in reflected, rarely in normal or surficial, anticlines; in these initiated contemporaneous with, but not subsequent to the sedimentary cycle. As detailed studies of oil fields throughout the world progress, it is predicted that contemporaneous folding, one of the important factors in creating the Plains type of folding, will be recognized as one of the important controls in the accumulation of petroleum.

DESERT PLAINS

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ABSTRACT

This paper contains a general review of the six types of plains that are ordinarily found in deserts, considering them especially from the viewpoint of origin. The list includes pediments, bajadas (compound fans), lake bottoms (including playas), dip slopes, graded river flood plains, and aggraded river flood plains. Of these the first two are particularly characteristic of deserts and are far more widespread than the others. On account of the confusion which prevails in recent geologic literature regarding these dominant types, the author has outlined the characteristics of pediments and bajadas more fully and explained the means of distinguishing them from each other. Pediments are the normal results of erosion under stable conditions in the desert. The formation of Bajadas is induced by diastrophic movements, climatic change, and other interruptions of the normal cycle. Combinations of pediments and bajadas are rather common and require more care for their identification.

The most extensive topographic features of deserts are plains. Even in the mountainous part of Southwestern United States it is probable that more than three quarters of the desert is composed of plains rather than of mountains. It is generally conceded that these plains are not all of the same origin. Many writers have in the past offered interpretations of one or more classes of the plains, but there now appears to be need of a systematic description of the various types, and a statement of the criteria for recognizing and distinguishing them. Such criteria should assist in clearing up the prevailing confusion of ideas regarding desert plains that is to be found in nearly all textbooks and in most special papers on the arid regions.

As my opportunities for desert study have been limited mostly to the arid southwestern part of the United States, especially Nevada, California, Utah, and Arizona, my illustrations will be drawn largely from the American Basin and Range Province; but the reports of others indicate that the principles here discussed apply to most of the mountainous arid regions of the world.

Desert plains in Southwestern United States comprise five distinct types that are listed here in the apparent order of their areas.

1. Pediments (including fan-topped pediments)
2. Bajadas (compound fans)

3. Lake bottoms (including playas)
4. Dip slopes
5. River flood plains
   a) Graded
   b) Aggraded

There are also composite types formed by the combining of some of those named above. For purposes of description the foregoing order will be reversed.

Since rivers are abnormal features of deserts and have only sporadic distribution, their flood plains are necessarily of minor extent there. In the Basin and Range Province the Colorado and the Humboldt are the only river systems of note. A normal river flood plain, for which the term "river grade plain" would probably be more satisfactory, is well known as a narrow winding strip of plain essentially parallel to the surface of the river itself and subject to inundation at times of flood. Such plains are made by the side-cutting of the stream as it wobbles or meanders in its valley. They are approximately level in transverse profile and very nearly uniform in declivity in longitudinal profile. In arid regions the angle of the latter is commonly .05 to .25 degrees, depending chiefly on the size of the river. Such a plain is an erosional feature, a rock-floored plain, but the floor is always carpeted with alluvium. The alluvium normally corresponds in thickness to the depth of the flood channel of the river, and as it is the only thing seen, it has misled some observers into supposing that the plain itself is due primarily to aggradation rather than to lateral erosion.

The aggraded river plain, including the delta, is underlain by thick alluvial deposits and is too well known to require description here. In the desert it is quite as rare as the graded flood plain.

The processes of desert erosion are very selective in their action upon weak and resistant rocks. They search out the weak strata and strip them completely from the hard. Hence in districts where stratified rocks are flat or gently inclined, broad plains develop on the tops of the more resistant layers of such rocks as sandstone, limestone, and basalt from which the shales and tuffs have been removed. These denuded strata are often called "dip slopes." They can generally be recognized without difficulty by their strict conformity to

the hard strata. The plateaus of northern Arizona and Utah afford many good examples. In the Basin and Range Province they are relatively uncommon, because nearly all the rocks there have been folded and faulted more or less complexly.

Having considered briefly the less common types of desert plains, we may now give more attention to the three which are of chief importance—the lake bottom, the bajada, and the pediment.

Nearly every desert basin has its central playa—the bed of an ephemeral lake. Indeed it is certain that nearly all the playas have in former times been covered by more permanent lakes. They are so level that a sheet of water less than a foot deep may completely cover a plain five miles in diameter. It is doubtful whether any topographic feature of the earth's surface equals the playa in flatness. The typical large playas are underlain by level beds of clay locally alternating with salt and gypsum. The plain is perfectly bare of vegetation and presents a glaring buff or white surface. Thompson[1] has distinguished between the "dry playa," which is normally hard, buff in color, and smooth as a floor, from the "wet playa," which is soft under foot, coated with white efflorescent salts, and indicates the active discharge of ground water by evaporation. The latter variety, sometimes called the "salina," is less common than the dry playa. There is no difficulty in recognizing so distinctive and peculiar a feature as a typical playa, such as Rogers Dry Lake in the Mojave Desert of California. They are simple plains of lacustrine aggradation, more or less modified by deflation and solution.

The bottoms of large perennial lakes, such as Pleistocene Lake Bonneville in Utah, are also level and are underlain to depths of hundreds of feet by level beds of fine sediment. The deposits are somewhat different in character, being more sandy and silty than those of the typical playa, and containing calcareous layers of algal origin rather than salt beds; but the resemblances are more important than the contrasts.

In a normal desert basin the playas are separated from the rugged rock slopes of the mountain ranges by smooth inclined plains, re-

[1] David G. Thompson, "The Mohave Desert Region, California," *U.S. Geol. Surv. Water Supply Paper 578* (1929).

garding the nature and origin of which there is still some difference of opinion. Such plains have often been assumed to be due to aggradation by floods from the mountain canyons, but the assumption is dangerous and often proves to be unwarranted. They may be either erosional features underlain by rock which is merely carpeted with gravel, or they may consist wholly of deep accumulations of gravel as generally supposed. The former is the true "pediment," to use Bryan's[1] convenient term, and the latter is a compound alluvial fan, the bajada of Tolman.[2] Combined pediments and bajadas are also common.

The true bajada, being only a series of confluent alluvial fans along the base of a mountain range, has distinctive characteristics by which it may be recognized in spite of its superficial resemblance to the pediment. It is underlain entirely by gravelly detritus that is ill assorted and poorly stratified—the deposits made by torrents and mudflows. Individual layers of the detritus are parallel to the fan surface. Each fan element is the work of a single mountain stream which tends to divide radially from the apex of the fan. The occasional shiftings of such distributaries leave a radiate series of dry channels on the fan surface. The radial profile of a fan is gently but decidedly concave upward, ranging in declivity from a small fraction of one degree near the playa to five, ten, or more degrees at the mountain base. Parallel to the mountain range the convexities of the component fans impart to the bajada an undulating surface. This characteristic, which is one of the most distinctive, is impressed upon the traveler who follows along the border of such a range, for he alternately rises over a smooth convex curve and descends into an equally smooth depression with another convexity appearing beyond it.

Fans are much less uniform in gradient than pediments. They vary in declivity with the gradient and size of the parent canyon. Large deep canyons have broad fans of low gradient, whereas short precipitous ravines have small steeply sloping fans. The latter grade into landslide and mudflow dumps and even into talus cones. Ac-

[1] Kirk Bryan, "Erosion and Sedimentation in the Papago Country, Arizona: with a Sketch of the Geology," *U.S. Geol. Surv. Bull. 730* (1922).

[2] C. F. Tolman, "Erosion and Deposition in Southern Arizona Bolson Region," *Jour. Geol.*, Vol. XVII (1909), 136–63.

curate measurements of many large fans show that declivities of one-half to three degrees are common. Those of the short steep fans range up to ten or twenty degrees and in talus cones even to thirty-five degrees. The fan, and hence the bajada, is formed wherever ravines or canyons empty upon lowlands of gentler gradient.

The pediment, long confused with the bajada, is basically a very different thing. The history of its study in the United States is well outlined by Davis[1] in a recent paper. The pediment is a gently inclined plain cut by stream erosion indifferently across rocks of varying lithology and structure. Commonly it forms the broad approach to a mountain range, and hence Bryan's term has seemed appropriate. In that relation it simulates the bajada. Its most essential characteristic is that it is underlain not by a fresh accumulation of stream deposits but by older strata or massive rock that antedate the formation of the plain. Such strata may be unconsolidated and of fluvial origin but their deposition has long since ceased and they have been eroded to form a new surface—the pediment. The pediment is commonly overspread with a thin carpet of gravelly detritus. Generally this veneer of alluvium is thick enough to conceal the rock surface and therefore leads the unwary observer to diagnose the slope as a built feature, or bajada.

The profile of the plain parallel to the mountain range is not undulatory as in the bajada but is essentially level. The temporary streams of the pediment are rambling and braided (anastomosing) rather than radially divaricate. The radial profile is almost straight although like most stream profiles it is imperceptibly concave upward. The slope is therefore a slightly concave surface that can scarcely be distinguished by the eye from a plane. The declivities of pediments in the southwestern deserts of the United States range from one-half to seven degrees, with the average about two and one-half degrees. Few exceed three and one-half degrees. In contrast to the bajada the large and small embayments of the pediment, extending back into the range, differ in gradient but little from each other. This is due to the fact that all are at grade rather than below grade as in the case of the fan or bajada.

Pediments are graded plains due, in the writer's opinion, to the

[1] W. M. Davis, "Rock Floors in Arid and Humid Climates," *Jour. Geol.*, Vol. XXXVIII (1930), pp. 1–27, 136–58.

active sidewise cutting of desert torrents. The power of such occasional floods is well known to all who have spent much time in deserts. The damage done is often great, as is only too well realized by railroad and highway engineers who are charged with the duty of making the repairs. Geologically the rate of lateral cutting is rapid—apparently more so than most other processes of the desert. Abrasion is not the chief factor, since close jointing and subaereal decay have generally prepared loose rubble and sand that are easy for the flood to sweep away. Pediments are essentially compound graded flood plains excavated by ephemeral streams. As their growth corrodes the mountain mass they may eventually coalesce to form smooth graded domes to which Lawson[1] applied the term "panfan" (meaning "all fan")—a name that is etymologically unfortunate because these features are not concerned with alluvial fans at all. Of such a dome the best illustration that has been cited is the broad granite dome near Cima,[2] in southeastern California. The panfan is in fact the desert-inhabiting species of the genus peneplain—if a geologist may borrow the terminology of a biologist—and the higher gradient which distinguishes it is conditioned by aridity.

The pediment grows wider as the cycle of erosion progresses, until it may absorb most of the landscape. Hills and mountains are razed and even the bajadas that may have been made early in the cycle are planed off to the profile of stream equilibrium. In view of the widespread impression to the contrary, it cannot be too strongly emphasized that the pediment, and not the bajada, is the normal and inevitable form developed in the arid regions under stable conditions. It is not exceptional and peculiar, as it is still regarded even by some of the few geologists who have recognized it at all, but it is dominant, widespread, and characteristic of deserts in general, not only in the United States but also in Mongolia, Africa, and Australia.

The bajada or confluent fan slope is characteristic of disturbed

[1] A. C. Lawson, "The Epigene Profiles of the Desert," *Univ. Calif. Publ., Dept. Geol.*, IX (1915), pp. 23–48.

[2] W. M. Davis, "The Basin Range Problem," *Proc. Natl. Acad. Sci.*, XI (1915), pp. 387–92.

D. F. Hewett, unpublished report and geologic map showing that the panfan is underlain almost entirely by granite.

conditions. It can develop only where the normal graded slopes have been interrupted. Such disturbed profiles are typical of regions which have recently undergone faulting or warping. They are also produced on a lesser scale by most of the other accidents that happen to streams. Without attempting a full list, one may mention the obstruction of valleys by landslides and lava flows, the sapping of formerly graded slopes by waves, glaciers, and landslips, the lateral cutting by rivers, and the climatic and even less obvious changes that affect the equilibrium of streams.

Of these disturbing features earth movements are probably the most important in degree but not in extent. It seems doubtful whether the formation of bajadas thousands of feet deep is ever induced except by diastrophism. Thick deposits of gravel with bajada surfaces may then be considered presumptive evidence of recent crustal movement. It is probable that most of the great bajadas are associated with young fault scarps.

Thus far only simple pediments and bajadas have been considered. It is essential, however, to bear in mind the fact that actual geologic features are more generally complex than simple, and hence careful attention must be given to the composite features with which the desert landscape is well provided. In many parts of the Basin and Range Province the mountains are fringed with gentle slopes that have the general form of pediments but the surface deposits and convexities of bajadas. In some cases excavations reveal the fact that these features were originally pediments but that thin fans (50 to 200 feet deep) had been built upon them in consequence of some minor change of climate or other controlling conditions. These may be termed "fan-topped pediments." On the other hand there are bajadas which, after being formed, have been eroded to a graded condition and thus reduced to pediments.

It is these composite types that are most difficult to recognize because they display some of the characteristics of both bajadas and pediments. Furthermore, all gradations between the several types of desert plains exist, and hence the geomorphologist should be on his guard against accepting first appearance as conclusive evidence. Doubtless these complications have retarded the clear discrimination of simple pediments and bajadas as physiographic types.

The composite types may best be recognized where the plain has been invaded by canyons from outside, as along the Colorado River Valley between the Grand Canyon and Yuma. In such excellent exposures the facts are clear. Elsewhere information from wells may be used; but well-data are notoriously unreliable and must be interpreted with caution, because most of the records have been made by men untrained in geology and ignorant of its problems. In many cases volcanic ash has been called sand or clay, folded conglomerate has been recorded as gravel, and lava mistaken for granite. Fan-topped pediments may be identified even from surface contours but the method is difficult to apply convincingly.

In any physiographic study of mountains and deserts, it is of vital importance to distinguish between the various types of plains and especially between bajadas and pediments. The bajada is entirely the result of detrital accumulation. It is best developed in regions now undergoing crustal dislocation, but in regions of long stability it is necessarily rare. The pediment is a feature due entirely to lateral erosion and its importance increases as the cycle of erosion advances. Except upon very weak rocks that are rapidly graded, only small and discontinuous pediments need be expected in regions of crustal unrest. Since disturbance and quiet may alternate in time, and since other modifying conditions such as climatic changes have their own appropriate effects, one must be prepared to find fan-topped pediments and other complex types that are often difficult to recognize.

STUDIES ON THE MORPHOLOGY OF THE HETEROSTRACI[1]

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ABSTRACT

This paper is chiefly a discussion of new morphological details exhibited by various members of the Heterostraci. A review of the Scottish Thelodidae is included, and a new occurrence of *Thelodus* from Canyon City, Colorado, is noted.

This paper is based upon a restudy of Traquair's original material and upon new collections recently made at the type localities. A few notes on Drepanaspis are included, as two specimens recently purchased by the Museum of Comparative Zoölogy show details worth figuring.

The Scottish Coelolepidae are the only ones known that give any clue whatever to the body form of this family. Specimens from other localities consist either of a mass of isolated scales, often water worn as in the Ludlow Bone bed, or else of irregular and shapeless patches of shagreen.

Traquair[2] restricts the family to two genera although earlier writers, notably Pander and Rohon, had distinguished several more solely on the basis of isolated scales. Because of the fact that several varieties of scales may be found on a single individual, *Thelodus* remains the only valid genus of the older descriptions. For this same reason, if additional complete individuals are found, many of the older species will likewise have to be abandoned.

Thelodus scoticus

T. scoticus is found in the Ludlow at Logan Water, and while no types were mentioned by Traquair,[3] Plate I, Figure 1, can be taken

[1] My thanks are due to Assistant Director Murray Macgregor and Mr. Donald Tait of the Scottish Branch of the Geological Survey of Great Britain for placing the material at my disposal, and for much assistance in the field. Professor P. E. Raymond has, as always, been most helpful with criticism and suggestions.

[2] R. H. Traquair, "Report on Fossil Fishes . . . . in the Silurian Rocks of the South of Scotland," *Trans. Roy. Soc., Edinburgh*, Vol. XXXIX, No. 32 (1899)

[3] *Ibid.*

as the holotype. The scales of the head, as in Traquair's figures, have crenulated margins, but in the specimens that I have observed the crenulations are fewer in number and are scalloped deeper into the margins of the scale. This type of scale is confined to the extreme top of the head. The second type is shown by Traquair in Plate I, Figures 8 and 9, and in this paper in Figure 1, *A* and *B*. The middle portion of the scale is elevated above the rest and slopes toward its center. The edges of this portion are slightly undercut. The scales are pointed posteriorly, and as one proceeds toward the tail they

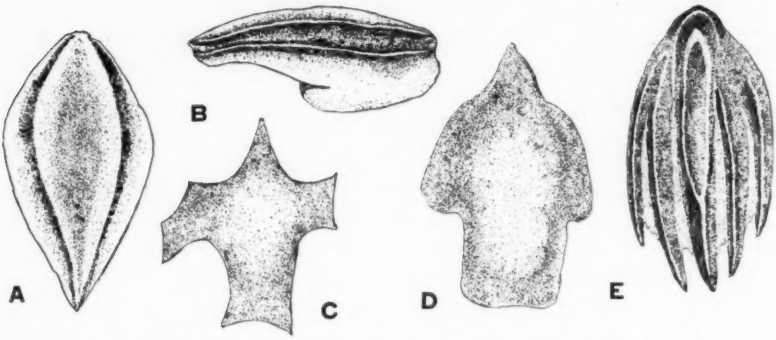

FIG. 1.—*A* and *B*, dorsal and lateral views of mid-body scales of *T. scoticus; C*, anterior scale of *T. taiti; D*, mid-body scale of *T. taiti*, anterior end at bottom; *E*, posterior scale of *T. taiti*.

become progressively longer and thinner and more acutely pointed. They are not absolutely symmetrical, and adjacent scales may vary somewhat in size. This species, as now defined, has been found so far only in the Ludlow, which is known to be a marine formation.

Thelodus planus

T. planus is another large species found only in the Ludlow. The type is the large complete individual figured by Traquair on Plate II of the same work, and was the only specimen known at that time. Since then I have found several individuals at Logan Water, though none of them is as complete as the type. The scales from all over the body are constructed on the same general plan, oval with smoothly convex crowns. They are somewhat pointed posteriorly

and overhang the base. The ratio of length to width varies somewhat, and there is also much variation in size. Figure 2, *A*, shows scales from the middle portion of the animal. They all have stout necks and bases. In cases where the crowns have been lost, the animal is covered with what appear to be diamond-shaped scales, and might easily be mistaken for another species.

This species exhibits to a marked degree a characteristic which seems to occur throughout the genus. The central portion of the body from the "pectoral fins" forward tends to break away from the expanded anterior "brim." Traquair's figure of the type shows this line of cleavage well established, but fortunately the specimen was collected entire. At Logan Water nodules are frequently found containing only the central part of the body minus the "pectoral fins" and the anterior rim of the head. This peculiarity gives the animal a fusiform appearance, and a false idea of its true body-form is thereby conveyed.

Thelodus taiti N.SP.

In the Downtonian is found a smaller *Thelodus*, which Traquair[1] considered might be another species. Because his material was inadequate he says, "To avoid premature multiplication of names, I associate them with the Logan Water examples which constitute the types of *Scoticus*." Through Mr. Tait's generous assistance I was able to obtain new material of this Downtonian form, and I therefore take pleasure in naming the new species after him. It should be remembered that Dr. Traquair obtained his fine material and was enabled to do his pioneer work on the Birkenidae and the Coelolepidae largely through Mr. Tait's careful, skilful collecting.

No specimen of *Thelodus* has yet been found sufficiently well preserved to give a detailed restoration of the squamation. Furthermore the dorsal and ventral sides and the flanks cannot be distinguished from each other with certainty. The position of the types of scales described below can only be an approximation. Great variation exists between individuals, probably depending upon how the specimen has been crushed.

The scales from the anterior part of the head are so irregularly scalloped that adjacent scales are very rarely exactly alike. Figure 1,

[1] *Ibid.*, p. 831.

C, may be taken as typical. As we progress posteriorly the scales gradually acquire the shape of an arrowhead. Figure 1, *D*, and 2, *C*, are good representatives of this type. Various modifications of this occur, as all the points may be lengthened or shortened.

The third type, Figures 1, E, and 2, *B*, occupies the posterior half of the body. The crown of the scale carries fine, longitudinal ridges

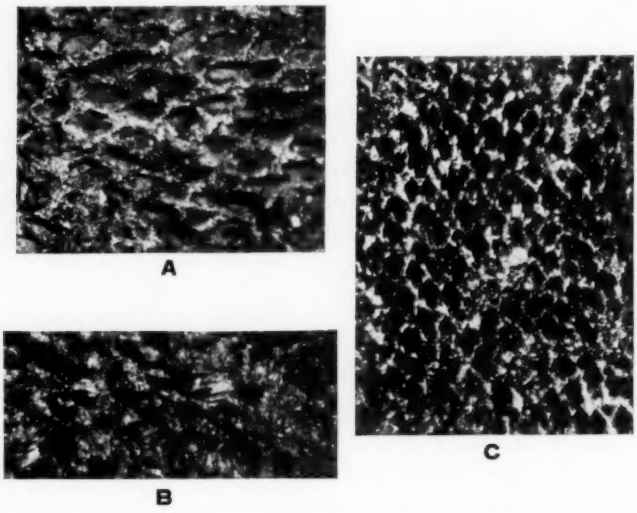

FIG. 2.—*A*, mid-body scales of *T. planus; B*, posterior scales of *T. taiti; C*, mid-body scales of *T. taiti*, anterior end at bottom. About 10×.

which project over the posterior end as short spines. The median ridge is the heaviest and has a small depression in its center. In the caudal region the scales become narrower, and the ridges more accentuated, and the spines longer. In the identification of any *Thelodus* one factor must be guarded against. The whole scale must be present. It is not always easy to be certain of this when they are as small as in *T. taiti*. Irregularly shaped scales, or scales with projecting processes, when broken obliquely in the rock, give many curious effects that are very misleading. The same situation occurs when only a part of the scale is present. For instance, in a counter-

part of a specimen of *T. taiti* the posterior scales often show only the longitudinal ridges of the crown imbedded in the matrix. If adjacent to broken parts of other scales, these ridges appear as very long, free spines projecting from the crown of the scale. These illustrations can be multiplied indefinitely. Reference to the figures will show clearly the innumerable combinations that a crushed and obliquely broken specimen can produce.

STRUCTURE

The individual figured by Traquair,[1] Plate I, Figure 4, No. 3903 in the Scottish Survey collection, as *T. scoticus* shows traces of internal structure. As defined above, this is now the type of *T. taiti*. Traquair makes no mention of this structure, and it probably escaped his attention as it is invisible unless the specimen is wet. There is a series of eight bars down either side of the head region, separated from each other, and from the tip of the "pectoral flap," by narrow channels (Fig. 3). These bars stand out black when immersed in alcohol or water because the scales are very closely set, and the channels appear lighter because the scales are sparser. This is not exactly the same structure as appears in *T. pagei*,[2] for in that specimen the bars run into the median line and meet a longitudinal bar, and, furthermore, the "pectoral flap" is situated posteriorly to this structure, which is not the case in *T. taiti*.

Patten[3] and Stensiö[4] find evidence of the branchial apparatus in *Trematas pis* and certain members of the Cephalaspidae. The former shows a semicircular row of branchial openings. The openings are not preserved in *Cephalaspis*, but there is found a series of internal chambers which Stensiö supposes to indicate gill pouches. These chambers run forward almost to the anterior end, which puts the forward ones even with the mouth. This is a peculiar condition unknown in every other group of animals, as the mouth is always dis-

[1] *Ibid.*

[2] Traquair, "On *Thelodus pagei*," *ibid.*, Vol. XXXIX, No. 21, Pl. I (1899).

[3] W. Patten, "Structure and Classification of the Trematas pidae," *Mem. Acad. Imper. Sci. St. Petersbourg* (8th ser., 1903), Vol. XIII, No. 5.

[4] E. A. Stensiö, "Downtonian Vertebrates of Spitsbergen," *Skrifter om Svalbard og Nordishavet* (Norske Videnskaps-Akad. Oslo, 1927), No. 12.

tinctly anterior to the entire branchial apparatus throughout the whole period of development.

Without attempting to discuss the validity of the arguments advanced regarding the branchial apparatus in the other two groups, as far as *Thelodus* is concerned, the evidence is insufficient to warrant anything more than pure hypothesis. The eight black bars (Fig. 3)

FIG. 3.—*Thelodus taiti* n.sp. (Geological Survey of Great Britain [Scottish Office], No. 3903). Anterior half of specimen showing internal structure. About 3×.

are certainly suggestive of the cartilaginous gill arches of the developing visceral skeleton of an Elasmobranch embryo, both in position and arrangement. There is no a priori reason why this should be the homologue of the chambers found in *Cephalaspis* any more than the homologue of a true visceral skeleton, which in fact it superficially resembles more closely.

Traquair[1] describes and figures two specimens of a *Lanarkia*-like

[1] "Supplementary Report on Fossil Fishes Collected . . . . in the Upper Silurian Rocks of Scotland," *Trans. Roy. Soc., Edinburgh*, Vol. XL, No. 33 (1905).

fish (Pl. II, Figs. 2 and 3) with markings which he thought might be indicative of branchial pouches. Two specimens figured by Lankester[1] as *Eukeraspis pustuliferus* show a row of chambers down the inner margin of the head shield. Both these instances lead one to the supposition that the chambers had something to do with the branchial apparatus, but as yet there is certainly no definite evidence concerning the gill structure itself.

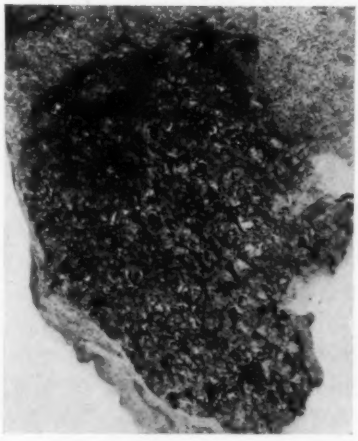

FIG. 4.—*Lanarkia horrida:* anterior end. The dark ring is composed of fine, close-set denticles, and borders the supposed mouth (M.C.Z., No. 5215). 2×.

THE MOUTH AND EYES

I have observed on several specimens of *Lanarkia horrida* a structure that might well indicate the mouth. The specimen from Birkenhead Burn figured by Traquair[2] in Plate III, Figure 1 (No. 3905, Scottish Survey), shows traces of it in the original, though not apparent in the illustration. M.C.Z., No. 5215 shows this feature exceptionally well. At the anterior border of what is thought to be the ventral surface of these specimens is a dark oval ring. Examination under a microscope shows that this ring is composed of numerous fine, closely set, thornlike scales similar in every way to the larger scales of the head and trunk. Underlying them is a black carbonaceous substance which might indicate underlying cartilage in which these scales were set, or which furnished some internal support. Inside the ring is bare matrix with no scales or carbonaceous matter. This structure is seen only on perfect specimens.

Equally well-preserved specimens sometimes show two circular patches of carbonaceous matter on either side of the body at the

[1] R. Lankester, *Fishes of the Old Red Sandstone* (Pal. Soc., 1870), Part I, Pl. XIII, Figs. 12 and 13.

[2] *Trans. Roy. Soc., Edinburgh*, Vol. XXXIX, No. 32 (1899).

extreme anterior margins. Traquair[1] figured two specimens showing these spots (Pl. I, Figs. 5 and 6) and interpreted them as eyes. I have examined both of these specimens, as well as several others of Mr. Tait's and my own collecting, and each showed only a circular spot of carbonaceous matter exactly as Traquair described it. There is no trace of a sclerotic ring, neither is there any indication of encircling scales. The eyes in *Drepanaspis* occupy a similar position, far out on the head. I have never observed these spots in the same specimens in which the hypothetical mouth is shown. Therefore if we may regard the eye spots as indicating the dorsal side, the mouth would then be either terminal or ventral.

THE TAIL

In *Lanarkia* the two lobes of the tail are very different. The axis of the body continues into the longer one, and the scale system of the body continues to the tip. The shorter lobe is closely set with very fine scales. Both lobes are very long and whiplike as contrasted with *Thelodus*. It is impossible to be certain whether the tail is heterocercal, or hypocercal as in the Anaspids. There is no system of dorsal scutes, nor are there any fulcral scales as in *Drepanaspis* to mark the median line. It is apparent, therefore, in an animal of depressed body form, and uniform squamation, that even when the dorsal surface is identified by the presence of the eyes one cannot tell which way the tail is lying. A small rounded fin is present on the posterior part of the body. Traquair figures it for *Thelodus*, and considers it to be dorsal. It is present also in *Lanarkia* (M.C.Z., No. 5216), and is covered by the same fine squamation that is found in the lower lobe of the tail. Unlike the Anaspids, the fin in this case is on the same side of the body as the largest lobe of the caudal fin.

The tail of a large *Thelodus*, probably *T. planus* (M.C.Z., No. 5217), shows a web connecting the two lobes for part of their length. When wet this structure is distinctly marked off from the lobes, and shows a series of eighteen or more parallel bars, caused by a grouping of the scales in parallel lines with spaces between. This might be taken to indicate cartilaginous fin rays. The rest of the web is covered with scales irregularly arranged, as distinct from the two lobes,

[1] "Supplementary Report, etc.," *ibid.*, Vol. XL, No. 33 (1905).

where the arrangement is regular. Traquair's[1] specimen (Pl. I, Fig. 1) appears to show a similar structure, poorly preserved, but he makes no mention of it.

The general shape of the caudal fin makes it seem probable that the tail was hypocercal, as in the Anaspids, rather than heterocercal, but the considerations are purely hypothetical. In undistorted specimens the long, whiplike lobe which contains the body axis always curves away from the smaller one. The fish looks more natural when the tail is placed with the long lobe curving down. If reversed, the same effect is produced as by Traquair's figures of *Birkenia*. The small fin on the posterior part of the body now becomes dorsal. This doubtless corresponds to the dorsal spine of *Drepanaspis*. Another bit of evidence is presented by *L. horrida*, M.C.Z., No. 5239. In this individual the eyes are visible and therefore the dorsal surface is uppermost. The smaller lobe of the tail appears to have been folded over the larger one, which would indicate that the tail was hypocercal.

THE MOUTH OF *Drepanaspis*

Kiaer,[2] in an important preliminary paper on the mouth of Pteraspids and Cephalaspids, considers the mouth of *Drepanaspis* to be terminal, as did Traquair, but confirms Dean in his opinion that the former had confused the dorsal and ventral sides. The fact that the mouth opening is apparently on the dorsal surface he explains as due to compression of the animal, and by a pushing-forward of the many small plates of the under side. Practically all specimens in which the mouth opening is apparent have been obliquely crushed. He further points out several parallels between the arrangement of the mouth parts in *Drepanaspis* and in *Pteraspis*, on which he has completed a remarkable dissection. In both cases the upper side of the mouth is bounded by the rostral plate (mental plate of Traquair) and the lower side by a series of small oral plates (rostral plates of Traquair). He also mentions a peculiar ridge on the left side of the front edge of the rostal plate as possibly being part of the maxillary plate. He points out further that the oral plates seen in ventral as-

[1] *Ibid.*

[2] J. Kiaer, "Structure of the Mouth of the Oldest Known Vertebrates," *Palaeobiologica* (1928), Band I.

pect were incorrectly figured by Traquair, and that there undoubtedly was a median element.

In all probability the presence of the mouth on the dorsal surface is natural, and is not due to distortion. No ventral surface ever shows it, nor are any of the tooth plates described below ever visible from the ventral side. Two specimens in the Museum of Comparative Zoölogy, and one in the American Museum of Natural History, throw additional light on certain of these structural details. M.C.Z., No. 5218 (Fig. 5) shows a specimen in which the mouth is relatively

FIG. 5.—*Drepanaspis gemündenensis:* dorsal view showing well-formed mouth. Note the toothlike cones on the inner margins of the oral plates. The two ridges in front, and at either end, of the rostral plate may indicate the anterior margin of a maxillary plate (M.C.Z., No. 5218). Natural size.

undistorted. The mouth opening between the rostral and the oral plates is lined with very fine denticles. Kiaer[1] describes a similar situation in the mouth plates of *Pteraspis*. The scales may be set on the under side of the oral plates. It is more likely, however, that they are set in the integument lining the mouth, as the covering is continuous and there is no trace of the sutures. The inner margins of the oral plates are developed into a series of eight conical projec-

[1] *Ibid.*, p. 131.

tions (Fig. 5). The fine denticles of the mouth grade up on to them, and each tip appears to have the denticles fused. As we pass to the outer surfaces of the oral plates we find the large denticles, such as are displayed on other parts of the body. These toothlike cones undoubtedly helped in grasping and retaining food, and possibly were used to some degree in mastication. The plates themselves have been somewhat broken by a series of small faults, and give the appearance of being more numerous than they really are. None of the faults, however, passes through the apices of any of the cones.

FIG. 6.—*Drepanaspis gemündenensis:* ventral view (see Fig. 7). M.C.Z., No. 5219. Natural size.

The peculiar ridge appearing just beyond the anterior margin of the rostral plate, upon which Kiaer comments, turns out to be paired. Furthermore, the denticulation grades from coarse to fine on the inner surfaces, much as in the oral plates. His suggestion that this may be the front edge of a maxillary plate, much as in *Pteraspis*, seems to me very plausible. It is doubtful if further dissection of a flattened specimen such as that in Figure 5 would show very much. However, one could probably be found with the rostral plate displaced.

M.C.Z., No. 5219 is a specimen showing the ventral aspect with practically no distortion. The median element in the oral plates is plainly visible, and the whole arrangement differs markedly from

Traquair's reconstruction. The large median plate is more or less wedge shaped with a backward-projecting tongue. There also appears to be a groove down the middle of the broad anterior end. This might be considered the result of unskilful preparation, were it not for the fact that it also shows on a good specimen in the American Museum of Natural History, No. F-1930. 1. This specimen has been somewhat obliquely crushed, and this median oral plate has been cracked and presents an unsymmetrical appearance. Nevertheless it is sufficiently well preserved to show a recognizable similarity. Doubtless here, as in the cranial plates of Anaspids, considerable variation in the shapes of plates can be found. In the American Museum specimen what is probably the anterior edge of the rostral plate is visible ahead of the median oral plate.

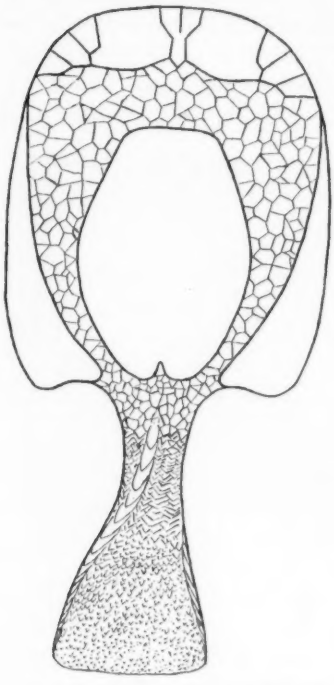

FIG. 7.—*Drepanaspis gemündenensis:* ventral view, drawn from the specimen in Fig. 6. The tail is drawn from M.C.Z. No. 5238. This restoration differs from previous ones by the addition of a median oral plate, and in the shape and arrangement of the other oral plates.

THE CANYON CITY BONE BED

The histology of the exoskeleton has been clearly demonstrated by Kiaer[1] in both *Drepanaspis* and *Psammosteus*. Tubercles of dentine are set over a layer of cancellous bony tissue. He does not mention enamel but doubtless it was present. The tubercles themselves are much like the denticles of *Thelodus*, with the basal layer of bone omitted. Some are stellate, others oval.

[1] "Upper Devonian Fish Remains from Ellsmere Land," *Videnskabs-selskabet i Kristiania, Rpt. 2nd Norw. Arct. Exp. Fram*, No. 33 (1915).

A study of thin sections has been made of specimens recently collected from the Upper Ordovician "bone bed" at Canyon City, Colorado, by Mr. Norman Hinchey. In fragments which have been properly stained by iron, the dentine tubercles of the surface denticles can be observed branching from the large pulp cavity exactly as in typical Elasmobranch dentine. There is a clear, colorless layer over the surface of each denticle which could be enamel, as this substance might be too dense to take a stain. There is a basal layer of cancellous bonelike tissue which in places appears laminated, and in which fine lacuna-like spots appear. Jaekel considered these spots to represent true osteoblasts. On the whole, conditions are very unfavorable for the preservation of detailed microscopic structure. On weathered surfaces the ornamentation of the plates shows well. Smoothly convex and stellate tubercles are present, exactly like those of the Devonian Drepanaspids and Psammosteids. Taking everything into consideration, we may assume that these animals are true members of the foregoing groups.

From the same weathered surfaces, scales of *Thelodus* have been obtained. These are all diamond shaped and more or less elongate. The crowns are separated from the bases by a shallow neck. The entrance to a small pulp cavity is visible. The material is all badly water worn, like material from the Ludlow Bone bed. In fact, water-worn scales of *T. parvidens* from the latter horizon so closely resemble these Canyon City *Thelodus* scales that it is practically impossible to distinguish between them. I have refrained from giving these a specific name, because a species of *Thelodus* founded on a few scales would be meaningless. Its only value would lie in calling attention to the occurrence at this locality, an object which is obtained by recording this above.

CONCLUSION

The mouth structure of every group of ostracoderms except the Cephalaspidae is now known. All have a system of crushing or shearing plates, or denticles, probably dermal in origin. There is nothing in the structure of the mouths themselves to indicate that any one is suctorial. On the other hand, not one of them gives the slightest clue of any gnasthostome affinities.

The mouth of *Lanarkia* is ringed around with simple placoid

scales. This should be the most rudimentary mouth known, with the placoid scales already in position to become transformed into true teeth. Unfortunately there is no evidence that this transformation could have taken place, as it presupposes a true visceral skeleton. If the generally recognized system of relationships within the Heterostraci is correct, *Drepanaspis* gives us the next known stage in the evolution of this mouth. Somewhere along the line of this group the gnasthostomes may have branched off. *Lanarkia* and *Thelodus* would certainly be classed under what are supposed to be "primitive types," the most primitive, and therefore the most promising, of all the ostracoderms.

The upper Ordovician is an early date for so specialized a form as *Drepanaspis* or *Psammosteus*. The occurrence of *Thelodus* throws a somewhat better light on the matter in that it indicates a "simple" form to be at least as old as a very much "specialized" one. Some revision of ideas regarding the distribution of the ostracoderms in time is necessary, as from many aspects, anatomical as well as stratigraphic, it is becoming evident that they are a very ancient group.

Kiaer has hinted at possible Elasmobranch affinities for the Heterostraci, and as far as the histology of the exoskeleton is concerned, this group is the only one that shows a true Elasmobranch type.[1] We must, however, await Kiaer's forthcoming monograph on the Pteraspids for more definite proof. At present we may say that the structure of the mouth, the position of the orbits, and the structure of the exoskeleton are evidence enough to preclude any close relationship with the Cephalaspids.

[1] H. C. Stetson, "A New American Thelodus," *Amer. Jour. Sci.*, Vol. XVI (1928), pp. 221–31.

THE METHOD OF MULTIPLE WORKING HYPOTHESES[1]

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[This essay on methods of scientific thought appeared in the *Journal of Geology*, Volume V (1897), pages 837–48, under the heading, "Studies for Students." Since then it has come to be regarded by many as a classic of its kind and its influence has been far-reaching. Requests for copies of it are still frequently received, although the available supply was exhausted many years ago. In response to the continued demand and in the belief that the present generation should be familiar with it, this study for students is reprinted in its original form.—THE EDITOR.]

There are two fundamental modes of study. The one is an attempt to follow by close imitation the processes of previous thinkers and to acquire the results of their investigations by memorizing. It is study of a merely secondary, imitative, or acquisitive nature. In the other mode the effort is to think independently, or at least individually. It is primary or creative study. The endeavor is to discover new truth or to make a new combination of truth or at least to develop by one's own effort an individualized assemblage of truth. The endeavor is to think for one's self, whether the thinking lies wholly in the fields of previous thought or not. It is not necessary to this mode of study that the subject matter should be new. Old material may be reworked. But it is essential that the process of thought and its results be individual and independent, not the mere following of previous lines of thought ending in predetermined results. The demonstration of a problem in Euclid precisely as laid down is an illustration of the former, the demonstration of the same proposition by a method of one's own or in a manner distinctively

[1] A paper on this subject was read before the Society of Western Naturalists in 1892, and was published in a scientific periodical. Inquiries for the article have recently been such as to lead to the belief that a revision and republication are desirable. The article has been freely altered and abbreviated so as to limit it to aspects related to geological study.

individual is an illustration of the latter, both lying entirely within the realm of the known and old.

Creative study however finds its largest application in those subjects in which, while much is known, more remains to be learned. The geological field is pre-eminently full of such subjects; indeed, it presents few of any other class. There is probably no field of thought which is not sufficiently rich in such subjects to give full play to investigative modes of study.

Three phases of mental procedure have been prominent in the history of intellectual evolution thus far. What additional phases may be in store for us in the evolutions of the future it may not be prudent to attempt to forecast. These three phases may be styled "the method of the ruling theory," "the method of the working hypothesis," and "the method of multiple working hypotheses."

In the earlier days of intellectual development the sphere of knowledge was limited and could be brought much more nearly than now within the compass of a single individual. As a natural result those who then assumed to be wise men, or aspired to be thought so, felt the need of knowing, or at least seeming to know, all that was known, as a justification of their claims. So also as a natural counterpart there grew up an expectancy on the part of the multitude that the wise and the learned would explain whatever new thing presented itself. Thus pride and ambition on the one side and expectancy on the other joined hands in developing the putative all-wise man whose knowledge boxed the compass and whose acumen found an explanation for every new puzzle which presented itself. Although the pretended compassing of the entire horizon of knowledge has long since become an abandoned affectation, it has left its representatives in certain intellectual predilections. As in the earlier days, so still, it is a too frequent habit to hastily conjure up an explanation for every new phenomenon that presents itself. Interpretation leaves its proper place at the end of the intellectual procession and rushes to the forefront. Too often a theory is promptly born and evidence hunted up to fit in afterward. Laudable as the effort at explanation is in its proper place, it is an almost certain source of confusion and error when it runs before a serious inquiry into the phenomenon itself. A strenuous endeavor to find out precisely what

the phenomenon really is should take the lead and crowd back the question, commendable at a later stage, "How came this so?" First the full facts, then the interpretation thereof, is the normal order.

The habit of precipitate explanation leads rapidly on to the birth of general theories.[1] When once an explanation or special theory has been offered for a given phenomenon, self-consistency prompts to the offering of the same explanation or theory for like phenomena when they present themselves, and there is soon developed a general theory explanatory of a large class of phenomena similar to the original one. In support of the general theory there may not be any further evidence or investigation than was involved in the first hasty conclusion. But the repetition of its application to new phenomena, though of the same kind, leads the mind insidiously into the delusion that the theory has been strengthened by additional facts. A thousand applications of the supposed principle of levity to the explanation of ascending bodies brought no increase of evidence that it was the true theory of the phenomena; but it doubtless created the impression in the minds of ancient physical philosophers that it did, for so many additional facts seemed to harmonize with it.

For a time these hastily born theories are likely to be held in a tentative way with some measure of candor or at least some self-illusion of candor. With this tentative spirit and measurable candor, the mind satisfies its moral sense and deceives itself with the thought that it is proceeding cautiously and impartially toward the goal of ultimate truth. It fails to recognize that no amount of provisional holding of a theory, no amount of application of the theory, so long as the study lacks in incisiveness and exhaustiveness, justifies an ultimate conviction. It is not the slowness with which conclusions are arrived at that should give satisfaction to the moral sense, but the precision, the completeness and the impartiality of the investigation.

[1] I use the term "theory" here instead of hypothesis because the latter is associated with a better controlled and more circumspect habit of the mind. This restrained habit leads to the use of the less assertive term "hypothesis," while the mind in the habit here sketched more often believes itself to have reached the higher ground of a theory and more often employs the term "theory." Historically also, I believe the word "theory" was the term commonly used at the time this method was predominant.

It is in this tentative stage that the affections enter with their blinding influence. Love was long since discerned to be blind, and what is true in the personal realm is measurably true in the intellectual realm. Important as the intellectual affections are as stimuli and as rewards, they are nevertheless dangerous factors in research. All too often they put under strain the integrity of the intellectual processes. The moment one has offered an original explanation for a phenomenon which seems satisfactory, that moment affection for his intellectual child springs into existence; and as the explanation grows into a definite theory, his parental affections cluster about his offspring and it grows more and more dear to him. While he persuades himself that he holds it still as tentative, it is none the less lovingly tentative and not impartially and indifferently tentative. So soon as this parental affection takes possession of the mind, there is apt to be a rapid passage to the unreserved adoption of the theory. There is then imminent danger of an unconscious selection and of a magnifying of phenomena that fall into harmony with the theory and support it and an unconscious neglect of phenomena that fail of coincidence. The mind lingers with pleasure upon the facts that fall happily into the embrace of the theory, and feels a natural coldness toward those that assume a refractory attitude. Instinctively, there is a special searching-out of phenomena that support it, for the mind is led by its desires. There springs up also unwittingly a pressing of the theory to make it fit the facts and a pressing of the facts to make them fit the theory. When these biasing tendencies set in, the mind rapidly degenerates into the partiality of paternalism. The search for facts, the observation of phenomena, and their interpretation are all dominated by affection for the favored theory until it appears to its author or its advocate to have been overwhelmingly established. The theory then rapidly rises to a position of control in the processes of the mind and observation; induction and interpretation are guided by it. From an unduly favored child it readily grows to be a master and leads its author whithersoever it will. The subsequent history of that mind in respect to that theme is but the progressive dominance of a ruling idea. Briefly summed up, the evolution is this: a premature explanation passes first into a tentative theory, then into an adopted theory, and lastly into a ruling theory.

When this last stage has been reached, unless the theory happens perchance to be the true one, all hope of the best results is gone. To be sure, truth may be brought forth by an investigator dominated by a false ruling idea. His very errors may indeed stimulate investigation on the part of others. But the condition is scarcely the less unfortunate.

As previously implied, the method of the ruling theory occupied a chief place during the infancy of investigation. It is an expression of a more or less infantile condition of the mind. I believe it is an accepted generalization that in the earlier stages of development the feelings and impulses are relatively stronger than in later stages.

Unfortunately the method did not wholly pass away with the infancy of investigation. It has lingered on, and reappears in not a few individual instances at the present time. It finds illustration in quarters where its dominance is quite unsuspected by those most concerned.

The defects of the method are obvious and its errors grave. If one were to name the central psychological fault, it might be stated as the admission of intellectual affection to the place that should be dominated by impartial, intellectual rectitude alone.

So long as intellectual interest dealt chiefly with the intangible, so long it was possible for this habit of thought to survive and to maintain its dominance, because the phenomena themselves, being largely subjective, were plastic in the hands of the ruling idea; but so soon as investigation turned itself earnestly to an inquiry into natural phenomena whose manifestations are tangible, whose properties are inflexible, and whose laws are rigorous, the defects of the method became manifest and an effort at reformation ensued. The first great endeavor was repressive. The advocates of reform insisted that theorizing should be restrained and the simple determination of facts should take its place. The effort was to make scientific study statistical instead of causal. Because theorizing in narrow lines had led to manifest evils, theorizing was to be condemned. The reformation urged was not the proper control and utilization of theoretical effort but its suppression. We do not need to go backward more than a very few decades to find ourselves in the midst of this attempted reformation. Its weakness lay in its narrowness and its restrictiveness. There is no nobler aspiration of the human intellect than the

desire to compass the causes of things. The disposition to find explanations and to develop theories is laudable in itself. It is only its ill-placed use and its abuse that are reprehensible. The vitality of study quickly disappears when the object sought is a mere collocation of unmeaning facts.

The inefficiency of this simply repressive reformation becoming apparent, improvement was sought in the method of the working hypothesis. This has been affirmed to be *the* scientific method. But it is rash to assume that any method is *the* method, at least that it is the ultimate method. The working hypothesis differs from the ruling theory in that it is used as a means of determining facts rather than as a proposition to be established. It has for its chief function the suggestion and guidance of lines of inquiry—the inquiry being made, not for the sake of the hypothesis, but for the sake of the facts and their elucidation. The hypothesis is a mode rather than an end. Under the ruling theory, the stimulus is directed to the finding of facts for the support of the theory. Under the working hypothesis, the facts are sought for the purpose of ultimate induction and demonstration, the hypothesis being but a means for the more ready development of facts and their relations.

It will be observed that the distinction is not such as to prevent a working hypothesis from gliding with the utmost ease into a ruling theory. Affection may as easily cling about a beloved intellectual child when named a "hypothesis" as if named a "theory," and its establishment in the one guise may become a ruling passion very much as in the other. The historical antecedents and the moral atmosphere associated with the working hypothesis lend some good influence, however, toward the preservation of its integrity.

Conscientiously followed, the method of the working hypothesis is an incalculable advance upon the method of the ruling theory, but it has some serious defects. One of these takes concrete form, as just noted, in the ease with which the hypothesis becomes a controlling idea. To avoid this grave danger, the method of multiple working hypotheses is urged. It differs from the simple working hypothesis in that it distributes the effort and divides the affections. It is thus in some measure protected against the radical defect of the two other methods. In developing the multiple hypotheses, the effort is to bring up into view every rational explanation of the phe-

nomenon in hand and to develop every tenable hypothesis relative to its nature, cause, or origin, and to give to all of these as impartially as possible a working form and a due place in the investigation. The investigator thus becomes the parent of a family of hypotheses; and by his parental relations to all is morally forbidden to fasten his affections unduly upon any one. In the very nature of the case, the chief danger that springs from affection is counteracted. Where some of the hypotheses have been already proposed and used, while others are the investigator's own creation, a natural difficulty arises; but the right use of the method requires the impartial adoption of all alike into the working family. The investigator thus at the outset puts himself in cordial sympathy and in parental relations (of adoption, if not of authorship) with every hypothesis that is at all applicable to the case under investigation. Having thus neutralized, so far as may be, the partialities of his emotional nature, he proceeds with a certain natural and enforced erectness of mental attitude to the inquiry, knowing well that some of his intellectual children (by birth or adoption) must needs perish before maturity, but yet with the hope that several of them may survive the ordeal of crucial research, since it often proves in the end that several agencies were conjoined in the production of the phenomena. Honors must often be divided between hypotheses. One of the superiorities of multiple hypotheses as a working mode lies just here. In following a single hypothesis, the mind is biased by the presumptions of its method toward a single explanatory conception. But an adequate explanation often involves the co-ordination of several causes. This is especially true when the research deals with a class of complicated phenomena naturally associated but not necessarily of the same origin and nature, as, for example, the Basement complex or the Pleistocene drift. Several agencies may participate not only but their proportions and importance may vary from instance to instance in the same field. The true explanation is therefore necessarily complex, and the elements of the complex are constantly varying. Such distributive explanations of phenomena are especially contemplated and encouraged by the method of multiple hypotheses and constitute one of its chief merits. For many reasons we are prone to refer phenomena to a single cause. It naturally follows that when we find an effective agency present, we are predisposed to be satisfied

therewith. We are thus easily led to stop short of full results, sometimes short of the chief factors. The factor we find may not even be the dominant one, much less the full complement of agencies engaged in the accomplishment of the total phenomena under inquiry. The mooted question of the origin of the Great Lake basins may serve as an illustration. Several hypotheses have been urged by as many different students of the problem as the cause of these great excavations. All of these have been pressed with great force and with an admirable array of facts. Up to a certain point we are compelled to go with each advocate. It is practically demonstrable that these basins were river valleys antecedent to the glacial incursion. It is equally demonstrable that there was a blocking-up of outlets. We must conclude then that the present basins owe their origin in part to the pre-existence of river valleys and to the blocking-up of their outlets by drift. That there is a temptation to rest here, the history of the question shows. But on the other hand, it is demonstrable that these basins were occupied by great lobes of ice and were important channels of glacial movement. The leeward drift shows much material derived from their bottoms. We cannot therefore refuse assent to the doctrine that the basins owe something to glacial excavation. Still again it has been urged that the earth's crust beneath these basins was flexed downward by the weight of the ice load and contracted by its low temperature and that the basins owe something to crustal deformation. This third cause tallies with certain features not readily explained by the others. And still it is doubtful whether all these combined constitute an adequate explanation of the phenomena. Certain it is, at least, that the measure of participation of each must be determined before a satisfactory elucidation can be reached. The full solution therefore involves not only the recognition of multiple participation but an estimate of the measure and mode of each participation. For this the simultaneous use of a full staff of working hypotheses is demanded. The method of the single working hypothesis or the predominant working hypothesis is incompetent.

In practice it is not always possible to give all hypotheses like places, nor does the method contemplate precisely equable treatment. In forming specific plans for field, office, or laboratory work,

it may often be necessary to follow the lines of inquiry suggested by some one hypothesis rather than those of another. The favored hypothesis may derive some advantage therefrom or go to an earlier death, as the case may be, but this is rather a matter of executive detail than of principle.

A special merit of the use of a full staff of hypotheses co-ordinately is that in the very nature of the case it invites thoroughness. The value of a working hypothesis lies largely in the significance it gives to phenomena which might otherwise be meaningless and in the new lines of inquiry which spring from the suggestions called forth by the significance thus disclosed. Facts that are trivial in themselves are brought forth into importance by the revelation of their bearings upon the hypothesis and the elucidation sought through the hypothesis. The phenomenal influence which the Darwinian hypothesis has exerted upon the investigations of the past two decades is a monumental illustration. But while a single working hypothesis may lead investigation very effectively along a given line, it may in that very fact invite the neglect of other lines equally important. Very many biologists would doubtless be disposed today to cite the hypothesis of natural selection, extraordinary as its influence for good has been, as an illustration of this. While inquiry is thus promoted in certain quarters, the lack of balance and completeness gives unsymmetrical and imperfect results. But if, on the contrary, all rational hypotheses bearing on a subject are worked co-ordinately, thoroughness, equipoise, and symmetry are the presumptive results in the very nature of the case.

In the use of the multiple method, the reaction of one hypothesis upon another tends to amplify the recognized scope of each. Every hypothesis is quite sure to call forth into clear recognition new or neglected aspects of the phenomena in its own interests, but ofttimes these are found to be important contributions to the full deployment of other hypotheses. The eloquent expositions of "prophetic" characters at the hands of Agassiz were profoundly suggestive and helpful in the explication of "undifferentiated" types in the hand of the evolutionary theory.

So also the mutual conflicts of hypotheses whet the discriminative edge of each. The keenness of the analytic process advocates the

closeness of differentiating criteria, and the sharpness of discrimination is promoted by the co-ordinate working of several competitive hypotheses.

Fertility in processes is also a natural sequence. Each hypothesis suggests its own criteria, its own means of proof, its own method of developing the truth; and if a group of hypotheses encompass the subject on all sides, the total outcome of means and of methods is full and rich.

The loyal pursuit of the method for a period of years leads to certain distinctive habits of mind which deserve more than the passing notice which alone can be given them here. As a factor in education, the disciplinary value of the method is one of prime importance. When faithfully followed for a sufficient time, it develops a mode of thought of its own kind which may be designated "the habit of parallel thought," or "of complex thought." It is contradistinguished from the linear order of thought which is necessarily cultivated in language and mathematics because their modes are linear and successive. The procedure is complex and largely simultaneously complex. The mind appears to become possessed of the power of simultaneous vision from different points of view. The power of viewing phenomena analytically and synthetically at the same time appears to be gained. It is not altogether unlike the intellectual procedure in the study of a landscape. From every quarter of the broad area of the landscape there come into the mind myriads of lines of potential intelligence which are received and co-ordinated simultaneously, producing a complex impression which is recorded and studied directly in its complexity. If the landscape is to be delineated in language, it must be taken part by part in linear succession.

Over against the great value of this power of thinking in complexes there is an unavoidable disadvantage. No good thing is without its drawbacks. It is obvious, upon studious consideration, that a complex or parallel method of thought cannot be rendered into verbal expression directly and immediately as it takes place. We cannot put into words more than a single line of thought at the same time, and even in that the order of expression must be conformed to the idiosyncrasies of the language. Moreover, the rate must be incalculably slower than the mental process. When the habit of complex or parallel thought is not highly developed, there is usually a leading

line of thought to which the others are subordinate. Following this leading line the difficulty of expression does not rise to serious proportions. But when the method of simultaneous mental action along different lines is so highly developed that the thoughts running in different channels are nearly equivalent, there is an obvious embarrassment in making a selection for verbal expression, and there arises a disinclination to make the attempt. Furthermore, the impossibility of expressing the mental operation in words leads to their disuse in the silent processes of thought; and hence words and thoughts lose that close association which they are accustomed to maintain with those whose silent as well as spoken thoughts predominantly run in linear verbal courses. There is therefore a certain predisposition on the part of the practitioner of this method to taciturnity. The remedy obviously lies in co-ordinate literary work.

An infelicity also seems to attend the use of the method with young students. It is far easier, and apparently in general more interesting, for those of limited training and maturity to accept a simple interpretation or a single theory and to give it wide application, than to recognize several concurrent factors and to evaluate these as the true elucidation often requires. Recalling again for illustration the problem of the Great Lake basins, it is more to the immature taste to be taught that these were scooped out by the mighty power of the great glaciers than to be urged to conceive of three or more great agencies working successively in part and simultaneously in part and to endeavor to estimate the fraction of the total results which was accomplished by each of these agencies. The complex and the quantitative do not fascinate the young student as they do the veteran investigator.

The studies of the geologist are peculiarly complex. It is rare that his problem is a simple unitary phenomenon explicable by a single simple cause. Even when it happens to be so in a given instance, or at a given stage of work, the subject is quite sure, if pursued broadly, to grade into some complication or undergo some transition. He must therefore ever be on the alert for mutations and for the insidious entrance of new factors. If, therefore, there are any advantages in any field in being armed with a full panoply of working hypotheses and in habitually employing them, it is doubtless the field of the geologist.

REVIEWS

DISCUSSION OF REVIEW OF *GEOLOGY OF THE McCALLS FERRY-QUARRYVILLE DISTRICT, PENNSYLVANIA*

The *Journal of Geology* for July–August, 1930, published a detailed analytical review by H. E. McKinstry of the *Geology of the McCalls Ferry-Quarryville District, Pennsylvania*, by E. B. Knopf and A. I. Jonas, *U.S. Geological Survey Bull. 799* (1929).

Although the reviewer shows a keen appreciation of the problems of the area, he is evidently not thoroughly familiar with the geological literature that deals with eastern Pennsylvania. He has, therefore, made a mistake in his discussion of the subject to which the authors wish to call attention.

Mr. McKinstry emphasizes correctly the regional problem, i.e., the occurrence of a belt of phyllites,[1] schists, and gneisses that overlie the Cambrian and Ordovician[2] limestones and dolomites and are in places cut by pre-Cambrian intrusives. He cites Bascom's explanation of this anomalous relation, namely, that the phyllites overlying the carbonate rocks are Ordovician and separated by a thrust fault from the mica gneiss to the southeast that is intruded by igneous rocks. He also cites the work of Bliss and Jonas in the Doe Run and Avondale districts in which they explained the presence of the mica gneiss over a limestone, which they considered the equivalent of the Paleozoic limestone of Chester Valley, by a flat and folded overthrust worn through by erosion. He then cites a paper by A. C. Hawkins published in May, 1924, in the *American Journal of Science*, called "Alternative Interpretation of Some Crystalline Schists in Southeastern Pennsylvania," in which Hawkins calls attention to the gradational character of the change in metamorphism from schist to phyllite, which he considers to be due to the greater metamorphic action of deeply buried intrusives in places where the rock

[1] Although these rocks have in some places "scarcely passed the stage of slates" (*U.S. Geol. Survey Bull. 799*, p. 33) yet they are not described by the author as slates and the use of slates in this connection by the reviewer is unfortunate.

[2] The carbonate rocks of Chester Valley are Cambrian and Ordovician as proved by their fossil contents, therefore the comment of "highly probable" Cambro-Ordovician age by the reviewer is somewhat misleading.

is a schist rather than a phyllite. The reviewer states that "this view has been arrived at by Knopf and Jonas in their latest publication although no doubt they arrive at it independently as the bulletin under review does not credit Hawkins with proposing it."

If the reviewer had read the article by Hawkins, which he discusses at some length, he would have found on the first page of Hawkins' paper that, so far from the views of Hawkins having been arrived at by Knopf and Jonas in their latest publication, either independently or otherwise, the views of Knopf and Jonas as embodied in *Bulletin 799* had already been printed in the *American Journal of Science* in January, 1923, and that the paper by Hawkins in 1924 is in itself an answer to and a criticism of the discussion of metamorphism and stratigraphic problems by Knopf and Jonas in 1923. The essential part of Hawkins' interpretation in which he distinctly differs from Knopf and Jonas is that the sedimentary Glenarm series at Avondale is of Paleozoic age and similar to the sedimentary series in Chester Valley. The objection to this interpretation has been set forth by Knopf and Jonas in *Bulletin 799*.

The reviewer's statement that the authors "candidly admit that they have failed to find any direct evidence of faulting along the upper contact of the limestone" is somewhat unjustifiable, because on page 35 of *Bulletin 799* the authors describe direct stratigraphic evidence of thrusting in that the Wissahickon albite-chlorite schist and Peters Creek schist of the Glenarm series overlie previously folded rocks of Lower Cambrian and Ordovician age. There is, as stated on page 89, a conspicuous absence of brecciation along the thrust plane, but it is emphasized on page 35 that "the discordant contact of Glenarm rocks against folded strata of different stratigraphic horizons is structural evidence of the overthrust relation of the pre-Cambrian rocks to the underlying Paleozoic formations."

E. B. KNOPF
A. I. JONAS

U.S. GEOLOGICAL SURVEY

The Physiographical Evolution of Britain. By L. J. WILLS. London: Edward Arnold & Co., 1929. Pp. 376; figs. 154, pl. 1. 14 *s.*, net. New York: Longmans, Green & Co. $8.40.

"Physiographical" here practically signifies physical geological evolution, for this work treats of the geological development of Britain from the physical side, as contrasted with biological evolution. Primary objects in

this book are the study of processes and the nature of the environments under which the successive geological formations of Britain have come into being. The treatment is in three parts: I, "Basic Principles"; II, "The Post-Carboniferous Systems"; and III, "The Pre-Cambrian and Paleozoic Systems." Consideration of the post-Carboniferous systems precedes that of the older systems because of the relative simplicity and great completeness of the later record, an understanding of which facilitates the interpretation of the more obscure chronicles of the earlier periods.

To round out the general picture a chapter is devoted to the Alpine region and another to the Anglo-Parisian cuvette and the Brito-Icelandic igneous province. In fact, much of the tectonics is based upon interpretations developed by students of Alpine structures and the applications of these principles to the British Isles are instructive. The underlying causes of diastrophism are purposely passed over, but the author clearly has been influenced by Wegener's hypothesis, and the text is to be read with that in mind.

To geologists better acquainted with the more regular and symmetrical American continents than with gnarled and twisted Europe, it may seem that some of the conclusions on geosynclines are provincial rather than general in application. It is stated that in the center of a geosyncline, the conditions are oceanic and bathyal, whereas those to the sides are epeiric and neritic. Neritic sediments are stated to be thin and rarely folded. But the 30,000 feet of Paleozoic sediments laid down in the Appalachian geosyncline, and now in the folded Appalachian Mountains, are broken by many gaps in the record and comprise thousands of feet of continental deposits as well as the abundant shallow-water marine formations. Nor is there a distinct "foreland" to the west. Rather is it a case of a geanticlinal-geosynclinal couple, the continental border chains of Appalachia yielding sediments to the subsiding Appalachian trough alongside, these sediments thinning gradually westward into the interior. Appalachian folding affected principally the thicker deposits where geosynclinal sinking had been greatest, but the western structural front of the Appalachians apparently does not coincide with any sharp line of demarkation between a geosyncline and a foreland. The concept of a geosyncline as a Mediterranean between continents is quite different.

As is common in many European publications, little restraint is shown in placing a continent where the deep Atlantic is today. Taking such liberties with major relief features of the globe calls for very strong evidence. The thick Millstone grit of Northern England (pp. 319–24) is

taken by Wills to throw light on the question of the position of the northern continent (Atlantis). Kendall is quoted to show that the volume of rock which went to make up this formation was at least 12,500 cubic miles (area once covered at least 25,000 square miles with an average thickness of at least 2,640 feet). Exept for the inevitable loss of material through solution, etc., this amount of sediment would be furnished by stripping off 2,640 feet from an area 250×100 miles. The material for the Millstone grit is said to have come from the north or northeast (see Fig. 134, p. 320). This is precisely the site of the Caledonian Mountain system, more or less parallel with whose structural grain the main hypothetical river is shown to flow. Though the source of the material of the Millstone grit "lay to the north where now roll the waves of the Atlantic," these are not the waves of the deep Atlantic, but of the shallow seas on the broad continental shelf where we know for certain the long chains of Caledonian Mountains stood in Devonian and early Carboniferous times. Following a very different philosophy these ranges have been interpreted as the northwestern frame of the European continent, facing a deep Atlantic Ocean then as now.

Recognizing the complexity of our major geologic problems and the great differences in present interpretations, this painstaking assemblage of facts, logically handled, must contribute notably toward ultimate solutions. Each important portion of the globe seems to afford better evidence along some lines than can be obtained elsewhere. The present volume presents a wealth of information of vital importance which Britain contributes to general world studies. The reader finds himself going over its pages with much care, for the author has made the underlying principles stand out without obscuring them with an undue amount of local detail. The well-selected illustrations and the clear, concise treatment make this exposition of the physical evolution of Great Britain a very welcome addition to the geologists' working library.

R. T. C.

Die Gravimetrischen Verfahren der Angewandten Geophysik. By HANS HAALCK. Berlin: Gebrüder Borntraeger, 1929. Pp. 205; figs. 85. M. 16.80.

This work, which is No. 10 of a general series, presents the gravimetric methods of practical geophysics. The principles and mathematical theories involved in the different methods are clearly presented and the instruments used in the determinations are well illustrated.

R. T. C.

Geology of North Ayrshire. (Explanation of One-inch Sheet 22). By J. E. RICHEY, E. M. ANDERSON, and A. G. MACGREGOR. With contributions from E. B. BAILEY, G. V. WILSON, G. A. BURNETT, and V. A. EYLES; Paleontological Chapters by G. W. LEE, and R. CROOKALL; and an account of the Soils and Agriculture by R. A. BERRY, E. M. MELVILLE, and C. LOUDEN, of the West of Scotland Agricultural College. Pp. 398; figs. 42; pls. 10. Price ten shillings.

A summary of the geology and an account of previous research on the rocks of North Ayrshire are given in the first two chapters, and later chapters are devoted to the Downtonian, Lower Old Red Sandstone, Upper Old Red Sandstone, Carboniferous, and New Red Sandstone (?Permian) formations. Striking features in the geology of the district are the number of volcanic episodes of different ages and the wide range of petrographic types associated with these. Chapters treat also of the fauna of the Carboniferous rocks of North Ayrshire, and of the flora of the Ayrshire coal measures. An account of the glaciation of the district deals, among other subjects, with the fossiliferous beds of Pleistocene age found beneath the boulder clay near Kilmaurs and in Cowden Glen, and with the glacial-retreat phenomena so well illustrated in the Eaglesham and Darvel areas.

R. T. C.

The Mineral Industry of the Far East. By BORIS P. TORGASHEFF. Preface by Wong Wen Hao, Director of the Geological Survey of China. Shanghai: The Chali Co. Ltd., 1930. Pp. 500; statistical tables 270. $10.00 for United States, £2 for Great Britain.

This is a comprehensive report on the mineral resources and mining prospects of China, Manchuria, Mongolia, Japan, Korea, Formosa, Russian Far East, Philippines, and Indo-China. Its usefulness is increased by many maps and a very complete bibliography.

R. T. C.

Geology of Bear Island. By GUNNAR HORN and ANDERS K. ORVIN. "Skrifter om Svalbard og Ishavet," No. 15. Oslo, August, 1928. Pp. 152; text figs. 70; pls. 9; geologic map.

Bear Island, discovered by the Dutch in 1596 and long known for its Devonian coal, is the southernmost island of Svalbard, which is the name

given to the Norwegian possessions in the Arctic Ocean. It is situated on the continental shelf 240 nautical miles north of North Norway, and 120 miles south of South Cape, Spitzbergen.

The northern part of the island is a nearly level plain 30–40 meters above sea-level, but the southern and southeastern parts are mountainous. Urd Peak, which reaches an altitude of 536 meters, is the highest point, but the entire southern coast is a steep sea cliff from 300 to 400 meters high.

Although the area of Bear Island is only 68 square miles, more than 8,500 feet of sedimentary strata belonging to several different systems are exposed on it. Thus from the standpoint of paleogeography the stratigraphic sequence is of great importance. The salient features of the sedimentary column may be summarized in the table on page 172.

These stratigraphic divisions are essentially after Andersson and Holtedahl. Despite the very detailed work of Horn and Orvin and the accumulation of data obtained from a number of bore holes, the latter writers, singularly enough, have not seen fit to refine the earlier formational nomenclature. As a consequence, Hecla Hoek is still used as a formation name for 3,000 feet of diverse sedimentaries of Cambrian and Ordovician age, and Ursa sandstone is the term applied to the coal-bearing beds of both late Devonian and early Carboniferous age.

The tectonic movements recorded on Bear Island are (1) those which have only affected the Hecla Hoek rocks and are probably of Caledonian age; these Silurian disturbances are responsible for a set of faults (resulting from pressure applied from the northeast), which trend northwest and southeast; (2) late Carboniferous movements which are recorded by two important unconformities; and (3) post-Triassic disturbances, probably of Tertiary age, responsible chiefly for pronounced northward tilting, and later oscillatory movements. The Quaternary history of Bear Island is difficult to reconstruct as the only traces of the previous extent and movement of the ice are those of the very last stage of glaciation. Earlier Quaternary records, however, are seen in the traces of higher oceanic levels which are regarded as marking plains of marine denudation. These are found at elevations of about 35, 55, 105, and 145 meters, and correspond almost exactly with those recorded on Spitzbergen.

The coals of Bear Island have been known since 1609; and those of Devonian age are the oldest in the world which have been mined. The Misery series seams vary from two to twelve in number and are too irregular in thickness and distribution to be mined profitably except under extraordinary conditions. The Tunheim series contains three coal seams,

but mining has been confined to the lower one, which is about 27 inches thick. All of the coals of the so-called Ursa sandstone have a high carbon

Series	System	Formation		Thickness in Meters	Description
Triassic	Carnian	Unnamed		190	Myophoria sandstone with clay ironstone and thin limestone
		Disconformity?			
Carboniferous	Upper Carboniferous	Spirifer limestone		120	Highly fossiliferous limestone
		Unconformity			
		Cora limestone		50	Limestones and sandstones
		Unconformity			
		Fusulina limestone		75	Dark limestone
	Middle Carboniferous	Yellow sandstone		150	Yellow, calcareous, unfossiliferous sandstone
		Ambigua limestone		175	Gray limestone and some sandstone
		Red conglomerate		50–145	Chiefly conglomerate; some shales and sandstones
	Lower Carboniferous				
Devonian	Upper Devonian	Ursa sandstone	Unnamed	110–235	White and gray sandstones with thin coal near top
			Tunheim series	20	Sandstones, shales, and three coal seams
			Barren measures	105	Sandstones, shales, and conglomerates
			Misery series	85	Sandstones and shales with many coal seams
		Unconformity			
Ordovician	Middle Ordovician	Hecla Hoek	Tetradium limestone	240	Black limestone
			Younger dolomite	400	Gray dolomite
	Lower Ordovician		Slate quartzite	175	Green and red slates; quartzitic sandstones
?	?		Older dolomite	400	Gray dolomites, partly oölitic
Cambrian?	?				

ratio (77.7–80), a high ash content (9–16 per cent), and a relatively low calorific value (8,100–8,500). Active mining of Tunheim coal began in 1916 and continued until 1925, during which period 116,094 metric tons

were exported, though at a loss. Although there is no present intention of reopening the mines, the meteorological and wireless station has been found valuable for the prediction of Norway's weather, and will be maintained by the Norwegian government.

The *Geology of Bear Island* is an admirable piece of detailed geologic work. The report is well written, contains many columnar and cross-sections, and is accompanied by a detailed geologic map on the scale of 1:50,000. The large number of fine photographs, particularly the series of panoramic plates, gives one a clear picture of this desolate Arctic isle.

CAREY CRONEIS

Handbook of Paleontology for Beginners and Amateurs. By WINIFRED GOLDRING. *New York State Museum Handbook 9*, Part I. Albany, New York, 1929. Pp. 356; figs. 97. $1.50.

This *Handbook of Paleontology* was, as the title indicates, written for "beginners and amateurs," but it contains much information which will recommend it to many who scarcely would care to be classed with either of those groups. The book was prepared in response to numerous requests at the New York State Museum for a treatise on paleontology simple enough to be understood by those with no previous training, and yet comprehensive enough to give a rather complete picture of the entire field. The present volume attempts to answer fully the often-repeated question, "What is a fossil?" A companion publication in reply to the query, "What is a geological formation?" is also being prepared. Both of these handbooks were planned to answer the foregoing questions with especial reference to New York State, but Part I, at least, is sufficiently generalized so that the rather numerous citations of New York State Museum specimens will not detract from its usefulness to those who do not have access to that institution.

The handbook is divided into a number of sections, 42 pages being devoted to "Nature, Preservation, and Significance of Fossils," 4 pages to "How To Collect Fossils," 5 pages to the "Classification of Animals," 150 pages to the "Description of the Invertebrate Phyla," 63 pages to the "Description of the Vertebrata," 50 pages to the "Classification and Description of Plants," 5 pages to the bibliography, and 13 pages to the Index.

The book is well illustrated by photographs of a number of the New York State Museum habitat groups prepared by Henri Marchand under

the direction of Drs. Ruedemann and Goldring, and by numerous pen and ink drawings by Clinton Kilfoyle. Not only are the latter skilfully and uniformly copied, but they have been judiciously selected from a large number of sources and add greatly to the value of the publication. The report is, in general, well written and easy to read, but the introductory divisions are not as lucid as the descriptions of the animals and plants, and, in a few places, they might well have been revised for both grammar and construction. The classification of the animal kingdom, given on pages 66–67, is fairly orthodox, but the Rhizopoda are given the rank of class, whereas they are quite generally recognized as a subclass under the class Sarcodina; and both the Foraminifera and Radiolaria are referred to the Rhizopoda, although there is a growing tendency to place the Radiolaria under the subclass Actinopoda. In addition, Actinozoa is used as the class term for corals, sea anemones, and related forms instead of the more widely accepted Anthozoa; and the Ostracoderms are incorrectly referred to as aberrant sharks.

The descriptions of the invertebrates, which form the bulk of the volume, are excellently handled, and constitute the most valuable part of the handbook. A few criticisms, however, may be directed at this portion of the publication. In the discussion of the Crustacea, the following sentences (occurring in the same paragraph) are likely to be misleading to the "beginner": "Trilobites had their origin in Precambrian times. . . . ." "Trilobites are restricted to Paleozoic times." In the list of important insect localities, the famous Elmo, Kansas, occurrence is not mentioned; and the various classes of the phylum Echinodermata are described in a sequence departing very notably from that in accepted usage. But these and other criticisms of similar nature are of little consequence compared to a rather grievous error in the descriptions of the Cephalapoda, where the Nautiloids are described as having calcareous and the Ammonoids noncalcareous protoconchs—essentially the reverse of the actual situation.

The descriptions of both vertebrate animals and plants are somewhat more abbreviated than those of the invertebrates, but in the main they are sufficient for the purposes of the New York State amateur, for whom they were especially written. In these sections Miss Goldring seems hesitant to admit that the Ordovician ostracoderm remains are bona fide, but states that bacteria "are known even in variety from the Precambrian." This is an interesting swing between conservatism and liberalism, as few paleontologists question the ostracoderm character of the

Canyon City chordate fragments, and fewer still agree that bacteria in variety are known as fossils in pre-Cambrian strata.

The handbook is well printed and of convenient size, but it needs rebinding for rough usage. The Index, though abridged, is serviceable, and the bibliography has been selected with care. A number of copies of this publication are doing service as reference books for the paleontologic portion of the University of Chicago Geology Survey course, and the book has found considerable favor with students and instructors alike.

CAREY CRONEIS

Paleozoic Corals of China. Part I, *Tetraseptata.* By AMADEUS W. GRABAU. Geological Survey of China, *Palaeontologia Sinica*, Series B, Vol. II, Fascicle 2. Peking, 1929. Pp. 175; pls. 6; text figs. 22.

Ten years have elapsed since Professor Grabau became chief paleontologist of the Geological Survey of China. In that decade the *Palaeontologia Sinica* has grown from an idea to one of the most important paleontological publications now in existence. During this period Grabau and his associates have not only elucidated the general features of the stratigraphy and paleontology of an area nearly as large as the United States, but they are already starting to elaborate on the details. In order to carry on this work Grabau has surrounded himself with, and in part trained, a corps of eager and competent assistants such as Sun, Chow, Chao, Tien, Ping, and others; and he has been fortunate in having the aid of Wiman, Halle, Lee, and Black in the capacity of honorary research associates. It is interesting to know that, despite the great amount of work already accomplished, the plans for the future are even more elaborate, and that Professor Grabau, although now nearly a complete invalid, is attacking new problems with much of his former vigor.

One of the most important of Grabau's researches recently completed is that dealing with the Chinese Paleozoic corals. In the publication here reviewed, which is his second contribution to the knowledge of Chinese streptelasmoid corals, he describes twenty new species and establishes the following new genera: *Gerthia*, *Bradyphyllum*, *Sochkineophyllum*, *Sinophyllum*, and *Allotropiophyllum*. *Gerthia* is a new genus of the Permian family Polycoelidae, which like *Polycoelia* lacks both tabulae and dissepiments, but which is distinguished from that genus by the marked acceleration of its counter quadrants, and by its thickened septa. The

genus *Bradyphyllum* includes simple streptelasmoid, mid-Carboniferous corals without distinctive columella, but with solid centers due to the strong thickening of the septa. *Sochkineophyllum* is a Permian genus including simple conico-cylindrical corals with the counter septum reaching the center, and with counter quadrants accelerated. Tabulae are well developed, and there is an incipient siphonofossula in the region of the cardinal septum. *Sinophyllum* is a Permian genus closely related to *Lophophyllum*. *Allotropiophyllum* is a new generic term for Carboniferous corals similar to *Amplexus*, but with deep calyx, with a cardinal fossula only (the other primaries not being well differentiated), with phyllotheca formed by the junction of the septal ends, and, finally, with the cardinal gap bridged by dissepiments.

New families defined are Laccophyllidae, Lophophyllidae, and Hapsiphyllidae; new sub-families are Tachylasmainae, Plerophyllinae, and Sochkineophyllinae. In addition, because of new information obtained from serial sections, it became necessary to emend the descriptions of the families Petraiidae, Lindströmiidae, Streptelasmaidae, and Cyathaxonidae.

A valuable four-page table included in this fascicle shows the distribution and range of the twenty-four genera and sixty-two species described in this and the earlier fascicle. The text is well written, and is essentially devoid of the typographical errors which mar some of the other fascicles of this series. A number of the generic and specific descriptions, however, would have been improved had the differences between the species and genera described and their nearest relatives been emphasized. The text figures are illuminating, and the plates, which are the result of the artistry of Mr. K. C. Liu, leave little to be desired, though undoubtedly some of the beauty of the original drawings has been lost in the reproduction. Like the other publications of the *Paleontologia Sinica*, this fascicle lacks an Index, and the rather extended Table of Contents fails to make up for this deficiency.

The Geological Survey of China, Professor Grabau, and the editors of *Palaeontologia Sinica*, Messrs. Ting and Wong, are to be felicitated on the general excellency of this and others of their publications. The scientific world is further indebted to them for publishing the results of their researches in English and German rather than in the Chinese, which might be expected as a result of the present strong nationalistic policies of the Chinese government.

CAREY CRONEIS

Gabb's California Cretaceous and Tertiary Type Lamellibranchs. By RALPH B. STEWART. Special Publication No. 3. The Academy of Natural Sciences of Philadelphia, Philadelphia, 1930. Pp. 314; pls. 17. $3.50.

Stewart's present paper is the logical sequel to his earlier (1927) revision of *Gabb's California Fossil Type Gastropods.* These two noteworthy publications establish him as the logical American successor to William H. Dall and Henry A. Pilsbry in the study of the more recent Mollusca. As a matter of fact, Stewart has profited from the guidance of the latter authority throughout much of his work. The courage to attempt such a difficult task as to bring order out of the chaos of molluscan nomenclature, however, and the still more rare ability to carry the work through to successful completion are, of course, Stewart's alone.

The lamellibranch revision comprises a most elaborate consideration of all the literature involved, with complete references and bibliographies of species and genera. In addition, seven new genera and twenty-two new subgenera are defined. The writer himself apologizes for the large amount of space devoted to discussions of problems of nomenclature, but he, of course, is in no way responsible for the fact that he found the literature bristling with such problems. Stewart, moreover, writes more lucidly than many of his contemporaries, and handles the most involved of nomenclatorial muddles skilfully and clearly. It is too much to expect, however, that all of his decisions in such matters will be regarded as final, particularly since he has in some instances deliberately departed from the international rules of nomenclature. In this connection the writer shows himself to be worldly wise when he somewhat cynically says, "Whether these notes will bring us any closer to a universal nomenclature may be questioned."

It is to be regretted that a major piece of research so generally excellent should be marred by a number of short cuts in the editing. There is no more than the poorest excuse for a Table of Contents. This is a list of twelve major headings into which the publication presumably is divided. No page references are given, however, and the last item, headed "List of Authors Cited by Date of Publication," apparently includes the general description of species, which follows the author list immediately (on p. 45), and continues to the Index (on p. 309). There is no general index, and the Genera and Species Index was compiled for the gastropod revision as well as for the present publication. It is recognized that the material described was difficult to photograph, but nevertheless the results as shown

in the plates are not all that could be desired. Furthermore, the magnifications are unwieldy, as many specimens are listed as $\times 1\frac{1}{2} \times 1\frac{1}{4}$, or $\times 2\frac{1}{4}$ with no uniformity of magnification on a single plate. The explanations of the plates are also inadequate, and no reference is made to text descriptions. A further criticism of the work is that Stewart, a very careful worker, is intolerant of slovenly efforts on the part of others, and many of his criticisms, although certainly well founded, are perhaps a trifle too acid.

CAREY CRONEIS

Earth Flexures. By H. G. BUSK, M.A., F.G.S., F.R.G.S. "Cambridge Geological Series." Cambridge, England: University Press, 1929. Pp. 106; figs. 92. $4.00.

This book concerns itself with earth flexures, their geometry, and their representation and analysis in geological section with special reference to the problem of oil-finding. Its prime object appears to be the reproduction of folds and flexures in geological structure-sections with geometrical exactness whereby oil geologists may then find the magic spot without fail.

The vast differences of English and American usage and meanings for words is accented in the title. To Busk the word "flexures" apparently means all kinds of folds. Bailey Willis, on the other hand, in *Geologic Structures*, page 17, limits flexures to the effects of warping. He says, "It is better to call the effects of warping *flexures* and to restrict the terms *folding* and *folds* to mechanical disturbances caused by compression." Busk, in his introductory statement, permits himself several broad generalizations concerning procedure in mapping oil-field structures which perhaps are valid for the foreign fields in which he has worked, but certainly do not appear to apply in the majority of American fields. He says:

> By tangential circular arcs we shall find that we can express any flexure from the surface evidence, whether it be a simple anticline or syncline, or with certain reservations, an overfold with its attenuated middle limb, while much can be done with geometrical instruments, whether thrusting or a known lateral variation in thickness be present or not.

In discussing sedimentation Busk minimizes lateral variation and concludes that sufficient uniformity exists in any one stratum for the use of his geometrically drawn structure-sections. He argues for "sedimentary rhythm," but fails to suggest a cause other than seasonal variation. He says, "Rhythm is so common that it must be the result of normal process in sedimentation, and not of diastrophic change, uplift and depression."

Rhythmic or cyclic sedimentation is not so common in America, but those descriptions of its occurrence in the Mississippian Chester series and in the Pennsylvanian, described by G. Marvin Weller in his article, "Cyclical Sedimentation of the Pennsylvanian Period and Its Significance," *Journal of Geology*, Volume XXXVIII, pages 97–135, and by R. C. Moore, in his address before the Geological Society of America in 1929, are considered as unusual. Weller considers the cycles to be initiated by uplift and separated by an unconformity from each other. Erosional unconformities between cycles scarcely argue for uniformity of thickness sufficient for the geometrical plotting used by Busk.

Busk finds the ordinary terms used in tectonic geology too loose for an exact science such as constructing sections by geometrical methods, and furnishes definitions of ten terms, namely; (1) axial or apical plane, (2) apex, (3) crestal plane, (4) crest, (5) trough, (6) anticlinal bend, (7) synclinal bend, (8) thickness on middle limb between anticline and syncline, (9) thickness on middle limb between anticlinal bend and synclinal bend, (10) amplitude. A discussion of competent and incompetent (similar) folding follows. Busk believes many folds are competent on one limb and similar on the other. He provides a formula indicating the amount of slippage between layers in a competent fold. He shows that in a group of beds 10 feet thick which are folded through two right angles in a mile, the total slip is about 30 feet or about 0.007 per foot, an amount thought to be unnoticeable. Reasoning from this, he believes many folds thought to be similar because of lack of evidence of slippage may actually be competent. He concludes that competent folding is much more common than similar and that the latter occurs only in intensely compressed regions. If it is accepted by the reader that competent folds are the rule, then the geometrical scheme for the construction of sections possesses possibilities of value.

In chapters iii and iv Busk gives twenty-one propositions, each of which he illustrates by formulas, diagrams, and structure-sections. The last six propositions are concerned with the proper location of the "curved axial plane." Busk seems to believe that inability to find the axial plane has been the reason for lack of success by many oil geologists.

Chapter v concerns itself with geological mapping for accurate section drawing and repeats here elementary cautionary instructions familiar to all conservative operators.

Chapter vi describes "flexures of Tertiary age in the petroliferous rocks of some extra-European countries," which represent examples from Burma, Southwest Persia, and the west coast of the peninsula of Sinai.

Three anticlines in Burma are discussed and diagrammed to show how the geometrical scheme of sectioning applies. One of the sections is drawn to a point 35,000 feet below the surface where the competent folds are shown to disappear. Another one is carried to a depth of 22,000 feet where the folds are drawn as competent. In all of these where attenuation is recognized, it is illustrated as occurring only near the surface and on one limb only. With increasing depth the beds are shown to be competent.

The structural problems which are unusual in Southwestern Persia consist of thrust sheets of gypsum which develop on the anticlines when the gypsum is exposed by erosion. These sheets spread laterally from the crest of the anticline and mask the syncline on either side. Where the gypsum flow develops as a reverse fault over one flank it is "gamma structure"; on both flanks it is "omega structure." "Iota structure" appears to have only the reverse fault and no flow. Although Busk says, "In structures such as those we have outlined geometric constructions for section drawing should be applied as far as possible," he presents none in his exposition of their form, and is content to illustrate them with poorly drafted imaginative sections of the usual type.

The discussion of the west coast of the peninsula of Sinai deals chiefly with rift-valley structure. He presents a stratigraphic section and divides the tension faults into two main types: (1) crescentic faults and (2) hinge faults. He says:

> The crescentic fault depends for its form on the fact that the upthrust block dips away from the fault face. Thus any change of strike in the direction of the dip of the upthrow block brings about a diminution of throw. The fault dies away in either direction by a change of strike in this sense. . . . . A hinge fault remains constant in strike over most of its distance, and its dying away is dependent upon the change of strike of the beds of the upthrow block.

Just how either a crescentic or hinge fault could form one of the escarpments of a continuous rift valley is not made clear, and in general the evidence brought forward for tensional faulting and rift origin of the escarpments appears to the reviewer to favor the ramp theory of Willis in the "Dead Sea Problem: Rift Valley or Ramp Valley," *Bulletin of the Geological Society of America*, Volume XXXIX, pages 490–542.

Even though structural control of the accumulation of petroleum in most American oil fields is faintly or definitely recognized, it is certain that, for many fields, porosity, unconformities, water relations, buried ridges, and other factors exert almost as much if not equally as much control. In structures where this is true drilling on the exact axial high is not

so necessary as Busk believes. Differential compaction in sediments in most American fields is now generally recognized, and this coupled with still other factors produces surfaces very different from those so conveniently assumed for geometric projection.

An examination of subsurface contour maps of typical Illinois, Oklahoma, Texas, or Kansas fields, drawn from data secured from closely spaced, carefully logged wells, shows many minor depressions and domes per square mile on generally broad, gentle folds of the theoretically competent type. Outside of the northern Rocky Mountain fields of North America and perhaps a few structures in California, it seems to the writer that Busk's geometrical propositions could scarcely be applied with success. In other more typical Tertiary oil fields, such as the California, South American, and the Baku provinces, Busk's geometrical scheme would fail to apply because the oil in most of these structures occurs in irregularly shaped zones rather than in particular strata.

The book is marked by a startling lack of reference to other geological papers, there being but nine references to other authors on geology, and an equally regrettable lack of familiarity with results of research published in American technical journals. On the whole, Busk appears to believe naïvely that the business of oil-finding consists of drilling on the exact axis of structures well marked at the surface. The illustrations, ninety-two in number, except for the geometrical diagrams drawn by instruments, are poorly executed. The value of this book to the average oil geologist depends upon whether or not competent folding is believed to be more prevalent than incompetent folding.

VIRGIL R. D. KIRKHAM

Sons of the Earth. The Geologist's View of History. By KIRTLEY F. MATHER. New York: W. W. Norton & Co., Inc., 1930. Pp. xv+272; figs. 83; pls. 8.

Parade of the Living. By JOHN HODGDON BRADLEY, JR. New York: Coward-McCann, Inc., 1930. Pp. 308.

Professor Mather and Professor Bradley have both written non-technically about the geological background of human life and history. The former has transcribed a series of lectures delivered before the Lowell Institute; the latter has compiled a series of essays, some of which appeared previously in magazines.

In *Sons of the Earth* Professor Mather carries the reader beyond the usual confines of historical geology: a chapter is devoted to "First Families of America" and another to "The Outlook for the Future." The body of the book is devoted to a recapitulation of organic evolution against the geologic background. The philosophic spirit of the author is indicated in his dedication: "To that unknown ancestor of mine who first considered the moral consequences of his own conduct. . . . ." In general the book reflects fairly and excellently the state of knowledge and the spirit of geology. Most geologists will not take issue with the facts and theories as the author presents them. (One inadvertant error would lead the reader to believe that the large dinosaurs weighed only two or three tons!) The author's style is straightforward, in places suggesting professorial condescension. The drawings by Schmitz contribute greatly to the attractiveness of the volume.

Professor Bradley writes in what appears to be a more popular vein, dedicating his book: "To those who are curious." He utilizes such provocative headings as "New Wine in Old Bottles," "Hobgoblins of the Flesh," "Pathways of Desire." His style is both breezy and sophisticated; some readers may object to it, others will be intrigued. The content of historical geology survives this popularization rather surprisingly. No illustrations are used, but a picturesque diagram of geologic time adorns the inside covers.

The reviewer would question Bradley's judgment in adopting a device, which is used not uncommonly in the geologic family circle, to make the results of paleontological study more vivid. Evolutionary changes are described in the active mood. The context suggests that the animal or plant activated and directed the change. Bradley did not commit the original sin in this respect, but it seems peculiarly unfortunate to have the fallacy presented to the layman. It is likely to give a false concept of the evolutionary processses, and it reflects untruly the spirit of the science.

Geology, in the minds of most laymen, is a science concerned with the material side of civilization. In the past Shaler, Tyndall, and Winchell, among others, pointed out the more humanitarian aspects of the science. Modern geology has need of the same interpretation. Mather's and Bradley's books assume significance in so far as they emphasize the contributions of geology to man's intellectual and social progress.

A. C. SWINNERTON

Methods in Geological Surveying. By EDWARD GREENLY and HOWEL WILLIAMS. London: T. Murby and Co.; New York: D. Van Nostrand; 1930. Pp. 420. 17*s.* 6*d.*

The reviewer found this to be an exceedingly interesting book, and recommends it to anyone who has actually made a detailed geological map, and who in so doing has enjoyed his labors. Its perusal by such a person will surely recall many experiences in interesting fashion. It is written "for those who desire to know how geological maps are made, rather than for those who wish to study their interpretation." The authors, one féels, have taken great pride in their maps. Their ideal is a work of science as well as a work of art; the former, because true maps are a product solely of induction, simply a convenient assembling of the observed facts; and the latter because Nature is a fit subject. The book is English, and stresses map-making on a scale of six inches to the mile, but the principles are of universal application.

The work discusses the origin and evolution of map-making, and the various uses of maps. Chapter viii is, so far as the reviewer knows, the only compendium giving the present status of geological map-making throughout the world. Most of the remainder of the work is used in describing just how a geological map is made: the things to look for, the instruments and symbols used for making and recording observations, and the related note-taking and collecting. There is a chapter on geological calculations, and one on correlation. These are succeeded by chapters on special problems in mapping, as follows: large igneous intrusions (following Cloos), crystalline schists, and superficial accumulations. The book is perhaps too philosophical for the average undergraduate; better works are available for those interested solely in plane-table structure mapping. Portions of the book have numerous American citations, and there is an extensive bibliography which is up to date.

D. J. FISHER

Diamond: A Descriptive Treatise. By J. R. SUTTON. London: T. Murby & Co., 1928. Pp. 118; pls. 35. 15*s.*

This little book attempts in quite successful fashion to appeal to both the general reader and the specialist. Crystallographic and physical properties are given along with elementary explanations of the terms used. South African diamonds are described in great detail, and those interested in the differences shown by stones from the various mines will find much on this subject. It is concluded that the genetic conditions involved

neither great pressure nor high temperature, that the mineral formed late in the crystallization sequence, and that it first separated out in plastic form.

D. J. FISHER

Allgemeine Palaeontologie. By JOHANNES WALTHER. Part IV: "Der Wandel des Lebens in Raum und Zeit." Berlin: Gebrüder Borntraeger. Pp. 551–809. M. 16.50.

Part IV of Walther's *General Paleontology* is devoted to the study of the change of life in space and time. The preceding volumes have the following contents: Part I, the fossils as enclosures in the rocks; Part II, the processes of life in geologic time; Part III, the geologic environment of the fossils.

The present volume discusses the following topics: the morphologic classification of organisms; the fossiliferous contents of the lithosphere; the geologic time table; the paleontologic zones as measures of time; life-partnership; facies horizon and life-space; the change of forms and the final form; the domain of water-breathers; the ocean space; transgressions and regressions; salt content in juvenile forms; the domain of the air-breathers; the spreading in terrestrial life; sun and life.

A great many problems of supreme importance to the paleobiologist can be found in this book. Most textbooks of paleontology give too little space to general biological problems and devote themselves almost entirely to matters of morphology or taxonomy. Here we have nothing but a general discussion, and it seems to us as if it might be more desirable to introduce more general biologic problems into the paleontology textbook rather than to treat biologic problems and classification independently in two textbooks of enormous size. It would have been very desirable if the author had given more quotations from the literature. His bibliographic references are rather meager.

A. C. NOÉ

Handbuch der Moorkunde. By KURD VON BÜLOW. Band I: *Allgemeine Moorgeologie: Einführung in das Gesamtgebiet der Moorkunde.* By KURD VON BÜLOW. Berlin: Gebrüder Borntraeger, 1929. Pp. xi+308; figs. 95; pls. 12. M. 30.

The present volume is intended as an introduction to the science of swamps and moors, for which it gives the geologic foundations. According to plan, the next two volumes will deal with the floristic and faunistic as-

pects of this subject; later volumes of the *Handbuch* will present economic aspects, a historical treatment of the subject, and a regional description of the swamps and moors of the earth.

The volume in hand is divided into the following main chapters: (i) "Petrography and Mineralogy of Moors"; (ii) "Petrogeny"; (iii) "Regional Distribution"; (iv) "Stratigraphy and Morphology"; (v) "Paleogeography"; (vi) "Economic Geology"; (vii) "Field Methods of the Investigation of Swamps and Moors."

Scattered throughout this volume are many very interesting discussions upon the origin of Paleozoic swamps and their relations to coal fields, climatic influences in relation to swamp formation, plant fossils, animal fossils and human fossils as revealed in swamps, problems of paleogeography, etc.

The entire *Handbuch* is expected to be completed in about six years. It will be a very useful reference-book, covering all features of the study of swamps and moors. The material on this subject is now widely scattered in a great many books and periodicals.

A. C. NOÉ

Statistisch-biostratigraphische Untersuchungen an Mitteljurassischen Ammomiten über Artbegriff und Stammesentwicklung. By ROLAND BRINKMANN. *Abhandlungen der Gesellschaft der Wissenschaften zu Göttingen Mathematisch-Physikalische Klasse.* (N.F.), Band XIII, Heft 3. Berlin: Weidmannsche Buchhandlung, 1929. Pp. vii+249; figs. 56; pls. 5. Rm. 22.

This book is a very interesting illustration of how statistical methods can be used to work out the phylogenetic-stratigraphic history of species in general. The author considers the purpose of a statistical biostratigraphy to be the exact conception of the distribution of fossil organisms in geologic time. Two factors are of main importance: the change of species' characters and the vertical distribution of the species in geologic time. He explains first his method, and afterward examines a number of types of ammonites in the light of his method. This is followed by a phylogenetic history of the ammonite types as deduced from his investigations, and at the end of his book he discusses several problems that might be solved by the application of his method. The author's discussion is very careful, convincing, and informative. There are innumerable paleontologic problems which should be approached from the statistical biostratigraphic point of view.

A. C. NOÉ

The Pleistocene of Northern Kentucky. By FRANK LEVERETT. Kentucky Geological Survey (6th ser.), Frankfort, Kentucky.

This bulletin contains five papers: the one designated by the title (81 pp.); "The Climate of Kentucky," by S. S. Vischer (88 pp.); "Geology of the Southern Part of the Dawson Springs Quadrangle," by A. H. Sutton (112 pp.); "The Cretaceous Deposits of Trigg, Lyon and Livingston Counties, Kentucky," by J. K. Roberts (56 pp.); and "The Geology and Physiography of the Mammouth Cave Natural Park," by A. K. Lobeck (74 pp.).

Leverett's report on the Pleistocene of northern Kentucky is a continuation of his previous work on the southern limits of the Pleistocene glaciation and deals largely with physiographic history in terms of drainage changes. He also discusses the glacially transported material, particularly the erratics, considering their source and the methods involved in their transportation, and some attempt is made to ascertain their age from the amount of weathering they have suffered. Deposits belonging to the Lafayette, Ohio River, and Irvine formations are discussed as to age and location, and all deposits which might be of commercial importance—as glass sand, molding sand, and gravel—are mentioned. One Appendix discusses the petrography of some of the erratics and another the fossils found in Big Bone Lick.

"The Geology and Physiography of Mammouth Cave Natural Park," by A. K. Lobeck, is an excellent study of the development of caves and sinks in a limestone region and of the resultant topography. The report contains many fine illustrations among which are a number of Lobecks' well-known sketches and block diagrams. The treatment of material is such as to be of especial value to elementary students and to the layman who plans to visit this region or is interested in this type of phenomena. While simple, and in general of an elementary nature, there is plenty of material which will prove of interest to advanced students.

JOHN T. MCCORMACK

Geochemie in ausgewählten Kapiteln. By W. J. VERNADSKY. Leningrad, translated from the Russian by DR. E. KORDES, University of Leipzig. Pp. 370. M. 25 bound; M. 23 unbound.

This book is unusual in geochemical literature as it deals with chemical processes exclusive of those which operate principally in ore deposits and it approaches them from the chemical rather than the geological standpoint. Ring formulas similar to those of organic chemistry are used with

inorganic elements. Iodine and bromine are discussed and little mention is made of the other halogens. Manganese is treated as a rock mineral instead of an ore as is customary, and no other metals, except iron and aluminum, receive more than casual mention. Coal and associated acids, both organic and inorganic, are discussed at length and considerable attention is paid to the rôle of organic material in the generation of gases—although no attention is given to oil or natural gas as end products. The chapter on radium and radioactive material is interesting as a compilation of data; but little new material is offered, and a discussion of helium is included in this chapter.

The larger part of this book is devoted to the discussion of silicate rocks, their weathering, and the products of this weathering such as free silica, kaolin, bauxite, and clays. Surprisingly little reference is made to specific localities—in fact the author deals largely in generalities.

JOHN T. MCCORMACK

Revision of Geologic Structure and Stratigraphy in the Ouray District of Colorado, and Its Bearing on Ore Deposition. By W. S. BURBANK, Colorado Scientific Society. Pp. 80; figs. 5; $0.50.

This publication is the result of co-operative work of the Colorado Metal Mining Fund, the State of Colorado, and the United States Geological Survey. It consists of a reworking of much of the material originally published in the *Ouray Folio.*

The only striking change in the stratigraphy is the establishment in this region of the Morrison formation, which is tentatively assigned to the Cretaceous, and in which are included the La Plata sandstone and the McElmo formation of the *Ouray Folio.* This revision is justified by recent correlation of beds and by new faunal evidence. A closer correlation between the mineral deposits and the intrusives results from this restudy and some new mineral bodies, not of commercial size, have been located.

JOHN T. MCCORMACK

Geology from Original Sources. By W. M. AGAR, R. F. FLINT, and C. R. LONGWELL. New York: Henry Holt & Co., 1929. Pp. 527; pls. 47; figs. 16. $3.75.

One is tempted to become overenthusiastic about *Geology from Original Sources.* The book does much to meet an increasingly apparent need for a suitable reference text for elementary students in geology.

To present to the student in convenient and interesting form the better portions of the great mass of geologic literature has ever been a problem to the instructor. The work of the foregoing authors does much toward overcoming this difficulty.

The book is exceptionally well written, interesting, and understandable to the layman as well as the scientist. The student will find inspiration in the liberally quoted writings of eminent geologists whose powers of narration and description make their writings literature as well as science. The book is so warmly alive with unusual examples, and analogies so aptly chosen, that one is scarcely aware of reading scientifically correct geology. The authors have collected, arranged, and welded together the writings and personal experiences of notable geologists, timely newspaper articles, and well-chosen passages from other scientific works. It is somewhat illuminating as to the character and scope of the material on which they have drawn to glance through the bibliography at the end of a chapter chosen at random. The bibliography of "Streams and Valleys," for instance, lists among others the following selections: Sir Charles Lyell, *Principles of Geology*, John Playfair, *Illustrations of the Huttonian Theory of the Earth*, an editorial from the *New Republic*, and an excerpt from Mark Twain's *Life on the Mississippi*.

The illustrations are outstanding and refreshingly original, which is much to be commended. Printing and "general make-up" of the book are satisfactory, while the price is kept within reason. Let us hope that this success will lead to the preparation of similar additional reference works in geology.

R. E. ESAREY

Geology and Mineral Resources of Kentucky. By W. R. JILLSON, State Geologist of Kentucky. *Kentucky Geological Survey*, Series VI, Vol. XVII (1928). Pp. 409; Pls., figs., and maps 251.

This publication can scarcely be classed as a contribution to the geology of Kentucky as it represents very little original work. The author has presented a summary of the geology of the state in a non-technical or popular form. The discussion is taken up by counties and consists of a brief review of the previous knowledge for each such unit, covering the physiography, stratigraphy, mineral resources, economic geology, etc. The illustrations are generally clear and well selected, but have appeared in previous publications, to a large extent.

It occurs to the reviewer that a short account of the regional geology of Kentucky as a whole would have provided a suitable background for

the report. Also, footnotes or references to available detailed reports should have been included for anyone desiring additional information upon any particular area. To one doing geological work in Kentucky for the first time, the book will provide a general orientation and it will serve excellently as a guidebook to the scientifically inclined traveler. No doubt the publication justifies itself in meeting definite requirements within the state.

R. E. ESAREY

Tables for the Determination of Minerals by Means of Their Physical Properties, Occurrences, and Associates. By E. H. KRAUS and W. F. HUNT (2d ed.). New York: McGraw-Hill Book Company, 1930. Pp. 266+ix. $3.00.

Except for the addition of a few minerals, the second edition of Kraus and Hunt's manual has retained the tables essentially as in the earlier edition. For those who are not familiar with the book, it may be mentioned that the tables are based upon a classification of the minerals according to metallic and non-metallic lusters, with subdivisions on the basis of color, streak, and hardness.

It is in the Introduction that the most striking changes have been made. The expansion of the discussions covering such generalities as luster, cleavage, fracture, and the like, to include pertinent definitions such as were formerly found only in the Glossary, has rendered these descriptions much more convenient for reference. An excellent summary of cleavages, arranged according to the crystal systems, is an important addition. The Glossary itself has been enlarged.

Perhaps the most helpful new feature of the volume is the Table of Minerals, arranged according to their specific gravity, and including the chemical composition, hardness, and crystal system of the various species. It is truly an interesting and noteworthy addition, and should prove of considerable aid to the users of the manual.

W. C. KRUMBEIN

Glacial Geology and Geographic Conditions of the Lower Mohawk Valley. By ALBERT PERRY BRIGHAM. *New York State Museum Bull. 280.* 1929. Pp. 133; figs. 72; map.

This study covers four quadrangles, Amsterdam, Fonda, Gloversville, and Broadalbin. A description of the physiography is followed by a discussion of the Mohawk glacier, which is shown to have moved west-

ward. Conditions were found which favor stagnant, waste-covered ice in the Mohawk Valley. During glacial recession it is possible that waters drained over this area from Lake Warren time to the Lake Iroquois stage, though further detailed mapping to the westward must be completed before this can be fully established.

WILFRED TANSLEY

Topographic and Geologic Atlas of Pennsylvania. No. 5: New Castle Quadrangle. By F. W. DE WOLF. Pp. 238; figs. 17; pls. 17; map. *No. 27: Pittsburgh Quadrangle.* By MEREDITH E. JOHNSON. Figs. 28; pls. 32; map.

In both quadrangles the stratigraphy of the Coal Measures is considered in detail. Economic resources consist principally of coal, natural gas, and petroleum. The use of natural gas in the iron industry has greatly declined, due to increased cost, and it is now used chiefly as a domestic fuel. The total production of petroleum is small. An Appendix is given showing detailed sections of forty-four diamond-drill holes in the Pittsburgh quadrangle.

WILFRED TANSLEY

A Geographical Study of Coal and Iron in China. By WILFRED SMITH. University Press of Liverpool Limited; London: Hodder & Stoughton Limited, 1926. Pp. 83; text figs. 9.

A well-written discussion of the structure of China and the conditions of the area during the coal-forming periods begins the booklet and gives the reader a helpful background. Since the early overoptimistic reports of the mineral wealth of China, the tendency has been to underestimate the resources of the country. Smith's article shows that there are great areas of valuable coal and iron. A chapter on the historical geography of the deposits is given, and another chapter is devoted to a discussion of the effect on civilization of the coal and iron resources in various districts. The booklet is interesting both to the geologist and to the geographer.

C. C. B.

Explanation of the Geological Map of China, Taiyuan-Yulin Sheet. By C. C. WANG. Peking: *Geological Survey of China,* 1926. Pp. 50; pls. 2.

The Taiyuan-Yulin sheet is an area which lies mainly in Shansi province. This publication is the explanation of the map of the area which was prepared for the geological map of China. The work is little more than a reconnaissance. Jurassic rocks are reported for the first time, and some additions to the knowledge of the physiography are made. The results are set forth in English and in Chinese.

C. C. B.

The Disappearance of the Huronian. By T. T. QUIRKE and W. H. COLLINS. Canada, Department of Mines, Geological Survey, Memoir 160 (1930). Pp. iv+127; figs. 4; pls. 8; 2 colored geological maps.

The area treated in this report lies north of Georgian Bay and at the eastern edge of the Huronian subprovince of the Canadian Shield.

The area is divided into two contrasting portions by a definite and fairly straight line, running from Killarney on Georgian Bay, northeastward toward Lake Temiskaming. Northwest of the dividing line lie immense thicknesses of folded Huronian sediments, now in ridges having elevations up to 1,700 feet. Southeast of the line lies a lowland of granite and gneiss, forming a nearly featureless plain, 600–800 feet in elevation.

Two major problems are involved. One is the relation of the Grenville and the Bruce. It is suggested that the Grenville series is the marine equivalent of the continental Bruce deposits. The other problem gives its name to the memoir and receives very full consideration. The authors believe that the Huronian sediments originally extended much farther, but have lost their original character through a regional granitization or migmatitization, which occurred at depths of 6 miles or so below the surface. The present surface is thought to represent probably the deepest section now exposed anywhere on the earth. Patches of very highly metamorphosed sedimentary rocks, interpreted as Huronian, occur in the area of granite and gneiss; and the relations observed lead the authors to conclude that the gneiss is largely sedimentary rock, changed from its original state by a process of replacement not unlike that so familiar to students of ore deposits. The granite is thought to represent those parts of the sediments that became liquid and recrystallized.

B. C. FREEMAN

PUBLICATIONS RECEIVED

Annual Report of the Quebec Bureau of Mines for 1929. Part A, Mining Operations and Statistics; Part B, Report on the Oil and Gas Resources of the Province of Quebec, by William A. Parks; Part C, Report on the Geology of Bousquet-Cadillac Gold Area Abitibi district, by L. V. Bell and A. MacLean. Quebec: R. Paradis, 1930.

Feuille: Vallorcine. By MM. Paul Corbin and Nicolas Oulianoff. Paris, 1930. 20 fr.

Reports on Geological Collections from the Coastlands of Kenya Colony. By Miss M. McKinnon Wood. Monographs of the Geological Department of the Hunterian Museum Glasgow University. Glasgow: Jackson, Wylie and Co., 1930.

Revista del Museo de la Plata. By Dr. Luis Maria Torres. Buenos Aires: Imprenta y Casa Editora, 1930.

Russell Genero-Radiative Concept. By Walter Russell. New York: L. Middleditch Co., 1930.

The Soils of Irrigation Areas in Otago Central. By H. T. Ferrar. Department of Scientific and Industrial Research, Geological Survey Branch, New Zealand. Bulletin No. 33. W. A. G. Skinner, 1930. Paper cover, *10s.*; quarter-cloth, *12s. 6d.*

South America. By Clarence F. Jones. New York: Henry Holt & Co., 1930. $6.00.

Summary of Progress of the Geological Survey of Great Britain and the Museum of Practical Geology for the Year, 1929, Part I. With report of the Geological Survey Board and Report of the Director. London: His Majesty's Stationery Office, 1930. *2s.*

Topographic Map of the Gulf Coastal Plain of Texas. Arkansas Geological Survey, George C. Branner, State Geologist.

Twenty-third Annual Report (New Series) of the Geological Survey Office. Extract from the Annual Report of the Department of Scientific and Industrial Research, W. A. G. Skinner, 1928–29.

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